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MBA PROFESSIONAL REPORT

An Analysis of USMC Heavy Construction Equipment (HCE) Requirements

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June, 2003

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According to I&L, HQMC, the Marine Corps needs to re-evaluate current operational requirements for engineer construction equipment. Acquisition and force allocation levels for equipment have remained essentially at constant 1970's, Cold War levels. Because acquisition and allocation levels haven't changed at the same rate as personnel, there is a perception that much of the existing equipment is unnecessary. Impacts for supporting too much equipment are decreased readiness, increased maintenance requirements, and increased O&M costs. The objective of our MBA project is to identify the correct quantity of construction equipment required to support the future needs of the USMC, focusing on unit training and Marine Expeditionary Unit (MEU) deployment cycles. This study will also evaluate the cost effectiveness of various alternatives for supplying the right amount and mix of CE to support contingencies via the civilian industrial base (lease/purchase decision factors, as well as domestic/international supplier issues). Our group will perform a review of USMC CE acquisition history to determine how the Marines have procured engineer equipment. Additionally, we will determine the annual volume of equipment that has been purchased or otherwise procured from industrial sources and the expected life cycle of existing equipment owned by the Marine Corps. With this information, we will assess the ability and willingness of suppliers worldwide to provide needed equipment for replacement of expired gear or in support of emergent contingencies. Our objectives are to determine the correct amount and mix of construction equipment to maintain at the Battalion level and to identify some cost effective alternatives for supporting battalion operations and training requirements.

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AN ANALYSIS OF USMC HEAVY CONSTRUCTION EQUIPMENT (HCE) REQUIREMENTS

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AN ANALYSIS OF USMC HEAVY CONSTRUCTION EQUIPMENT (HCE) REQUIREMENTS

ABSTRACT

According to Installations and Logistics (I&L), HQMC, the Marine Corps needs to re-evaluate current operational requirements for engineer construction equipment. Acquisition and force allocation levels for equipment have remained essentially at constant 1970's, Cold War levels. Because acquisition and allocation levels haven't changed at the same rate as personnel, there is a perception that much of the existing equipment is unnecessary. Impacts for supporting too much equipment are decreased readiness, increased maintenance requirements, and increased O&M costs. The objective of our MBA project is to identify the correct quantity of construction equipment required to support the future needs of the USMC, focusing on unit training and Marine Expeditionary Unit (MEU) deployment cycles. This study will also evaluate the cost effectiveness of various alternatives for supplying the right amount and mix of CE to support contingencies via the civilian industrial base (lease/purchase decision factors, as well as domestic/international supplier issues). Our group will perform a review of USMC CE acquisition history to determine how the Marines have procured engineer equipment. Additionally, we will determine the annual volume of equipment that has been purchased or otherwise procured from industrial sources and the expected life cycle of existing equipment owned by the Marine Corps. With this information, we will assess the ability and willingness of suppliers worldwide to provide needed equipment for replacement of expired gear or in support of emergent contingencies. Our objectives are to determine the correct amount and mix of construction equipment to maintain at the Battalion level and to identify some cost effective alternatives for supporting battalion operations and training requirements.

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LIST OF ACRONYMS AND ABBREVIATIONS

AAO	Authorized Acquisition Objective
AIS	Automated Information System
A_O	Operational Availability
ASCII	American Standard Code For Information Interchange
BCY	Bank Cubic Yard
BTAM	Engineer Table of Authorized Material
CEB	Combat Engineer Battalion
CM	Corrective Maintenance
CMC	Commandant of the Marine Corps
CNA	Center for Naval Analyses
DC	Deputy Commandant
DC/S I&L	Deputy Chief of Staff (Installation and Logistics)
Div	Division
DL	Deadlined
DoD	Department of Defense
Eng	Engineer
EOT	Equipment Operating Time
ERO	Equipment Repair Order
ESB	Engineer Support Battalion
FMF	Fleet Marine Force
FOB	Forward Operating Base
FSSG	Force Service Support Group
FT	Fully Tracked
GAO	General Accounting Office
GCF	Grade Correction Factor
GSA	General Service Administration
HQMC	Headquarters, Marine Corps
I MEF	1st Marine Expeditionary Force
I&L	Installations and Logistics
II MEF	2nd Marine Expeditionary Force
III MEF	3rd Marine Expeditionary Force
IV MEF	4th Marine Expeditionary Force
JDPAC	John Deere Political Action Committee
lb	Pound
LBS	Pounds
LCC	Life Cycle Cost
LCY	Loose Cubic Yard
LE	Life Expectancy

LPE	Engineer Advocacy Center
LPV	Logistics Vision, Installations & Logistics
M&RA	Manpower and Reserve Affairs
MAGTF	Marine Air Ground Task Forces
MATCOM	Marine Corps Material Command
MBA	Masters of Business and Administration
MCBul	Marine Corps Bulletin
MCCDC	Marine Corps Combat Development Center
MCO	Marine Corps Order
MEB	Marine Expeditionary Brigade
MEF(s)	Marine Expeditionary Force(s)
MEU	Marine Expeditionary Unit
MIMMS	Marine Corps Integrated Maintenance Management System
MMEA	Personnel Management Division, Enlisted Assignments Branch
MOOTW	Military Operations Other Than War
MOS	Military Occupational Specialties
MPF	Maritime Preposition Force
MROC	Marine Requirements Oversight Council
MTBF	Mean Time Between Failure
MTBR	Mean Time Between Repair
MWSS	Marine Wing Support Squadron
NATO	North Atlantic Treaty Organization
NAVFAC	Naval Facilities Engineering Command
NORM	Normal Distribution
NPS	Naval Postgraduate School
NSN	National Stock Number
O&M	Operation and Maintenance
OA	Operational Allowance
OEM	Original Equipment Manufacturer
PEI	Primary End Item
PFI	Private Finance Initiative
PM	Preventive Maintenance
ROC	Required Operational Capability
S. D.	Standard Deviation
S/N	Serial Number
SLEP	Service Life Extension Program
SORTS	Status Of Resources and Training System
STDEV	Standard Deviation
T	Total Time Available
T/E	Table of Equipment

T/O	Table of Organization
TAM	Table of Authorized Materiel
TAMCN	Table of Authorized Materiel Control Number
TM	Technical Manual
Tp	Processing/Production Time
TRIA	Triangular Distribution
UNIF	Uniform Distribution
US	United States
USC	United States Code
USD A&T	Under Secretary of Defense for Acquisition & Technology
USMC	United States Marine Corps
WWII	World War II
YD^3	Cubic Yards (Volume Measure)

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Semper Fidelis

Major Christopher M. Zuchristian

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Lieutenant Commander Allen Blaxton

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Lieutenant Commander Michael J. Fay

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I. INTRODUCTION

A. BACKGROUND

In order for the Marine Corps to achieve future warfighting capabilities and relevancy in the joint environment, it must increase combat service support capabilities while at the same time reducing its logistics footprint. After the Gulf War, the Marine Corps recognized that changes in national interests resulting from the world's changing environment demanded a review of the Corps' warfighting capabilities. As a result of that review, the Marine Corps has a vision for the future that fundamentally changes the way logistics support is provided to the Marine Air Ground Task Forces (MAGTFs). The Commandant has defined the capabilities of an expeditionary force as:

> An agile and flexible force organized to accomplish a broad range of military objectives in a foreign country or region. Such a force must be able to deploy rapidly, enter the objective through forcible means, sustain itself for an extended period of time, withdraw quickly, and reconstitute rapidly to exercise follow-on missions.[1]

Although the MAGTF is capable of doing this today, we recognize that there is room for improvement.

Deputy Commandant (DC), Installations & Logistics (I&L) has publicly made the commitment of "enhancing the expeditionary and joint capabilities of the MAGTF through the evolution of logistics."[2] DC, I&L is responsible for the leadership, management, integration and modernization of worldwide Marine Corps logistics, engineering (focusing on engineer construction equipment), services, and installations.[3] As the Engineer Advocate for the Marine Corps, he is responsible for ensuring Marine Corps forces possess the necessary engineer capabilities to meet mission requirements. Engineer capabilities are those that provide mobility, counter-mobility, survivability and

[1] Commandant's Planning Guidance, FY2002

[2] United States Marine Corps Logistics Campaign Plan 2002,

[3] Biography, Lieutenant General Richard L. Kelly, Deputy Commandant, I & L, HQMC, Oct 2002

general engineering support necessary to support a MAGTF from the initiation of operations through the accomplishment of its mission.

In order to meet the Commandant's expectations for the future, I&L is conducting reviews on numerous programs and requirements. One such review, sponsored by the Engineer Advocacy Center (LPE), I&L and the subject of our Masters in Business and Administration (MBA) project, involves analysis of Marine Corps engineer construction equipment requirements. Engineer Construction Equipment are pieces of equipment used in horizontal construction (See Appendix A).

B. PURPOSE

The purpose of our research is to determine if the engineer community is able to reduce its current inventory and still meet contingency obligations. Specifically, we address the ability to quantify the level of inventory that should be maintained within the Marine Expeditionary Forces (MEFs). This project offers engineer planners a flexible decision support tool to provide advance planning information regarding the effects of changing inventory under a variety of conditions. Additionally, we address factors that are harder to quantify, such as lifecycle costs and contingency contracting. Finally, we determined a set of data points that must be maintained by the Marine Corps, if reliable analysis is to be conducted in the future.

C. SCOPE

Our scope for the MBA project is to provide I&L recommendations related to the following two objectives.

1. Determine the correct amount and mix of engineer construction equipment to maintain at the MEF level.

2. Identify cost effective alternatives for supporting MEF operations and training requirements.

The primary objective of the project is to determine how much equipment MEFs need to have on-hand to support their operational and training needs. Our focus will be on evaluating the operational allowance allocated to MEFs to perform their missions. We will use a variant of the Marine Requirements Oversight Council's (MROC) Table of Equipment (T/E) definition. Their T/E definition is as follows:

Table of Equipment = Operational Allowance (OA) + Maritime Preposition Force (MPF) [4]

Currently, MROC has not defined the OA portion of this equation; however they are in the process of soliciting input from the Commanders of each Marine Expeditionary Force. For the purpose of beginning our analysis, we will defined OA as the quantity of construction equipment required to be maintained at the MEF level for daily training plus the equipment required to support Marine Expeditionary Unit (MEU) deployment cycles. MPF will continue to be our wartime reserve, although the Commanders of the Unified Commands have the right to use the assets as they see fit. Any requirement for construction equipment above and beyond the OA quantities will have to be outsourced.

Our analysis will require a determination of what the expected capacity and productivity levels are for a MEF. Specifically we want to determine how much work a MEF should be able to perform with a typical piece of equipment, given certain manpower levels. Then we will determine how many of what type of equipment will be required to meet mission requirements. To help us answer this question, we will look to civilian construction companies to identify what their standard productivity is for each piece of equipment in our study. We think it is a reasonable assumption to extrapolate general civilian work unit standards to our problem, although most likely we will need to apply some sort of factor to the productivity standards to account for military circumstances. For example, Marines may work faster because they are under pressure, resulting in greater productivity, or they may work slower due to a myriad of factors such as weather, danger of sniper attack or fog of war.

A critical part of our analysis requires knowing how much equipment the MEFs currently have on-hand and how much it is being used. This information will help us to determine if, in fact, the Marine Corps is maintaining excess equipment and how much. We expect to collect at least three years worth of historical data related to the use of the existing equipment (hours of use, hours of maintenance, etc.). Additionally, we will

[4] Marine Requirements Oversight Council Decision Memorandum 02-2002, February 11, 2002

collect data pertaining to the training and operations these units performed in the last three years. Once the data is collected, we expect to be able to answer questions like "Did the MEF always have the equipment it needed on-hand? How much maintenance was due to operational use?

Our preliminary analysis of data will consist of comparing the expected use of the equipment based upon an assigned operational mission (or training requirement) and comparing that with actual use data. Progressive use of the data will lead us to build an optimization model for determining the most cost effective amount and mix of construction equipment to have at the MEF level.

Evaluating the capabilities of global suppliers to meet operational and training requirements of the USMC at home and abroad is also critical to our overall analysis. We considered alternatives such as leasing, buying and rental as means to reduce the USMC logistical footprint. There is the potential to reduce the USMC's logistical costs through the use of contingency contracting, requirement specific rentals, and other innovative means of real time delivery of commercially available construction equipment.. The ability of commanders to rent equipment to meet needs above the OA can provide a flexible, yet cost effective means to accomplish a short term mission.

D. METHODOLOGY

We used the information from the Marine Corps Integrated Maintenance Management System (MIMMS) and the Caterpillar handbook as the basis for our research. We also conducted a literature review of military doctrine and field manuals, technical magazines, web resources, previous graduate-level theses, and civilian manuals. Manpower information was gathered from Manpower Management Enlisted Assignments (MMEA), Manpower and Reserve Affairs (M&RA).

Next we designed five spreadsheet models that will aid engineer planners in identifying the desired capacity to be maintained within the MEF given certain variables (utilization, personnel, etc…). Each spreadsheet model has a second model accompanying it using the Crystal Ball software that identifies distributions. Our assumptions used to create the spreadsheet models were based on the Caterpillar Handbook and military technical manuals.

We addressed whether the United States Marine Corps (USMC) could improve its Life Cycle Management. Civilian and military methodologies were used to identify the life cycle costs of each of the subject pieces of equipment. Lastly, a comparison between leasing versus buying the equipment was conducted. Our intent was to see if more cost effective means of supplying heavy construction equipment to forward deployed troops in the future existed.

Lastly we have provided a list of recommendations, to include data points that should be maintained in MIMMS so future analysis can be conducted.

E. REPORT ORGANIZATION

The remainder of this project is organized as follows: Chapter II highlights the background to this equipment issue and identifies the sample pieces of equipment used for this project. Chapter III describes our readiness analysis. Chapter IV explains the methodology that we used to estimate capacity. Chapter V identifies military and civilian construction standards and their differences. Chapter VI discusses life cycle management. Chapter VII describes our cost benefit analysis. Chapter VIII presents our findings, recommendations and conclusion.

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II. BACKGROUND

> On November 10, 1775, - Which the Marines take as their birthday - the Continental Congress passed a resolution to raise two Battalions of American Marines. The battalions played traditional roles as prize crews, sharpshooters, and landing forces. – The Marine Corps Officer's Guide, 5th Edition[5]

A. INTRODUCTION

Prior to looking at the background of the situation, it is important to understand how the Marine Corps is organized and how the engineers play in the larger picture. The Marine Corps prides itself on being the *"Force in Readiness."* The Marine Corps can forward deploy to anywhere in the world and be self-supporting for 15-30 days without replenishment. It is not by coincidence that they can do this. It is because of their unique organization that allows them to be so self-reliant. This organization is the Marine Air-Ground Task Force (MAGTF). As you will see, the MAGTF is more than a philosophy; it is the cornerstone for the operational deployment of its forces.

B. ORGANIZATION

The Marine Corps doctrine normally dictates the employment of Marine forces as integrated MAGTF. The MAGTF doctrine emphasizes the employment of all elements of the force under a single commander, thereby obtaining unity of effort.[6] Due to its unique ability to task organize its forces; the Marine Corps can tailor the force to meet any contingency requirements. For the most part, the MAGTF is not a permanent organization; it is tasked-organized for a specific mission and dissolved upon the completion of the mission.

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5 *The Marine Corps Officer's Guide, 5th Edition,* 1989

6 The Marines, Marine Corps Heritage Foundation Beaux Arts Editions, 1998

Regardless the size of the MAGTF (See Figure 1), it will include the following four components:

- Command Element
- Ground Combat Element
- Air Combat Element
- Combat Service Support Element

Marine Air-Ground Task Force (MAGTF)

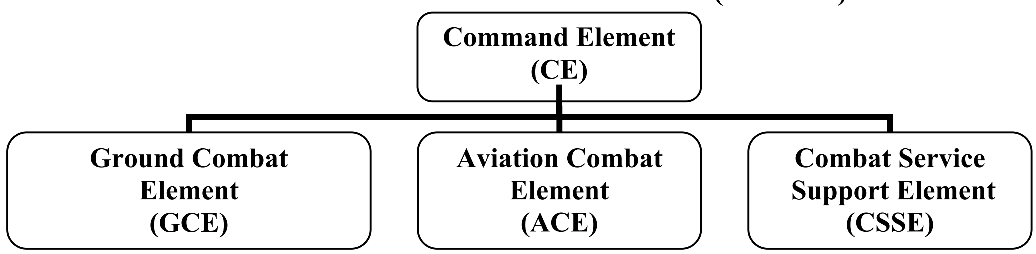


Figure 2-1: Marine Air-Ground Task Force (MAGTF)

Although the Marine Air-Ground Task Forces are task-organized to complete a variety of missions, there three basic types of MAGTFs: the Marine Expeditionary Unit (MEU), the Marine Expeditionary Brigade (MEB), and the Marine Expeditionary Force (MEF). Figure 2 shows the Typical Marine Air-Ground Task Forces (MAGTF).

Marine Expeditionary Force (MEF)	**Marine Expeditionary Brigade (MEB)**	**Marine Expeditionary Unit (MEU)**
Command Element	**Command Element**	**Command Element**
Marine Division (MarDiv)	**Regimental Landing Team (RLT)**	**Battalion Landing Team (BLT)**
Marine Aircraft Wing	**Aircraft Group**	**Composite Squadron**
Force Service Support Group	**Brigade Service Support Group**	**MEU Service Support Group**
Commander: Major General	Commander: Brigadier General	Commander: Colonel

Figure 2-2: Typical Marine Air-Ground Task Forces (MAGTF)

There are two MAGTFs that have standing headquarters; the MEU and MEF. The MEB is stood up as required. The MEU is the smallest of the standing MAGTFs and is usually considered the forward element of a larger MAGTF. The Marine Corps has at least two MEU's forwarded deployed ready to respond to mission in any climate and place around the world at all times. The other standing MAGTF is the MEF. The Marine Corps has three Active Duty MEFs. There are two MEFs located in the Pacific region (Okinawa and California) and one in the Atlantic region (North Carolina). It normally only deploys in total in support of war or major theater conflict.

The MEF consist of all four elements of the MAGTF; command, GCE, ACE, and CSSE. Within each of these elements, the engineer community has representation. In the Command element there are engineers on the staff to assist the commander to command, control, and coordinate his engineer efforts. In the other three elements of the MEF, there are engineer units assigned (See Figure 3).

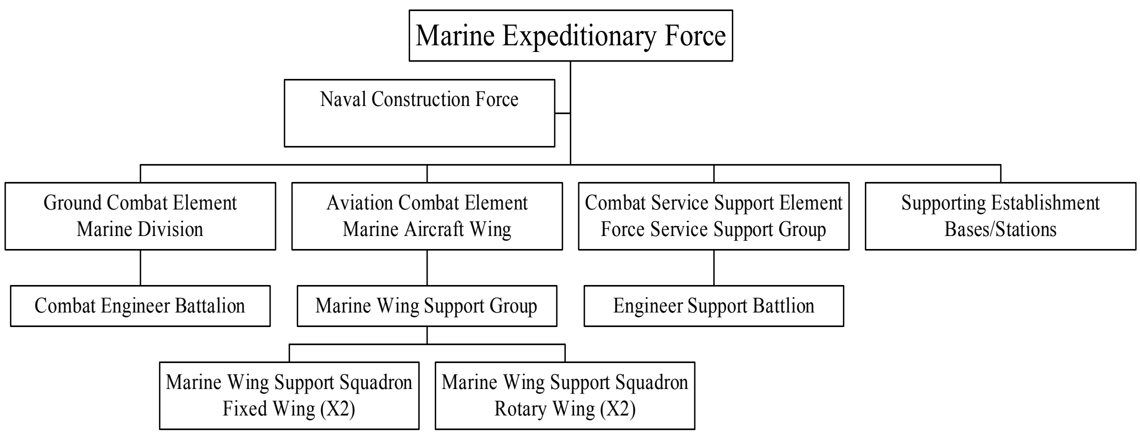


Figure 2-3: Marine Expeditionary Force Organizational Chart

Each engineer unit has unique missions it performs in support of its element, but there are areas that are common to all three.

C. HISTORY OF ENGINEERS

The need for engineers became visible when the Marine Corps was assigned the mission of seizing and defending advanced naval bases in 1931.[7] The intent was to provide the Marine Corps with its own construction, maintenance, and general service capability. From 1927 until 1935 engineers performed primarily base services and

[7] IBID

support functions.[8] In 1935 with the development of the Fleet Marine Forces, the first "force" engineer company was formed.[9] Its equipment, training and organization followed that of the Army Corps of Engineers. As you see throughout this project, the Marine Corps' equipment and doctrine used today is still closely associated with the Army Corps of Engineers.

As the Marine Corps began its huge expansion immediately prior to WWII, it was resolved that each Marine division would have an organic engineer battalion. Units were constantly changing throughout the war, task organizing for particular battles. During WWII, with the exception of the engineer assault companies, the employment of the engineer battalion in a purely combat support role was not considered. As a consequence no combat-oriented doctrine, training, equipment or organization was specifically developed.[10] The engineers' primary missions were building and maintaining bases and stations.

In Korea and Vietnam, the engineers continued to roles that were considered to be of a non-combat nature. They performed base and station construction, road construction and maintenance, and landing zone construction. Additionally, they provided general combat support such as deliberate road sweeps, direct combat support to a specific infantry unit for such missions as search and destroy.[11] But the main focus was the use of heavy construction equipment to construction forward operating bases in which the infantry battalions can defend key terrain for future operation.

In Desert Shield/Desert Storm, engineers, specifically heavy construction equipment, was used extensively through the preparation and execution of the war. Prior to the war, base camps and road networks were constructed. During the war, bulldozers were used to clear minefields, so that follow forces could maneuver through them safely; land zones where created in Kuwait in order to facilitate resupply; and Forward Operating Bases (FOB) were constructed in order to sustain the momentum. As history

[8] IBID

[9] IBID

[10] IBID

[11] "*Victory at High Tide*," Robert Debs Heinl, Jr., Colonel USMC, 1997, pg137

shows us, the Marine Corps is dependant on it engineers and their heavy construction equipment. Let's take a look at how Heavy Equipment evolved to what it is today.

D. EVOLUTION OF ENGINEER EQUIPMENT

As the Marine Corps engineers changed, so did heavy construction equipment. The United States at the turn of the twentieth century was making innovation starting with agriculture, which quickly was adopted in the construction industry. The specialization of earthmoving equipment, essentially as a function of haulage distance, giving rise to the grader, bulldozer, and scraper more or less between the 1880's and the end of the First World War.[12] Following the rapid pace of development during the thirty years or so preceding the war, the size and engine power increased, diesel engines became more or less universal, as did hydraulic systems. By the Second World War, construction machinery was more or less indistinguishable from that of today.

The first recognizable grader dates from 1886.[13]   It was pulled by an animal but is remarkably similar to the graders of today.

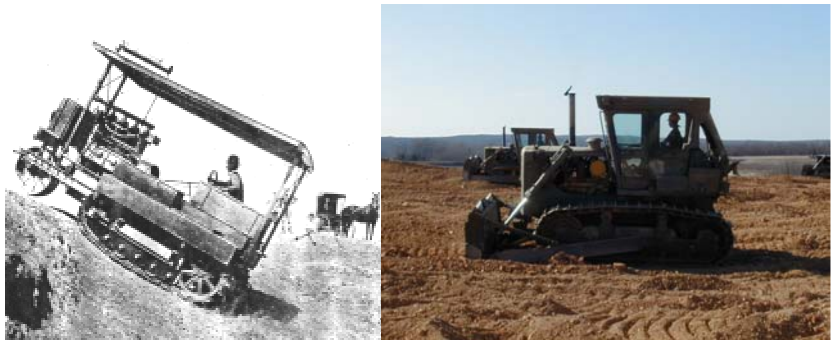

The history of the bulldozer begins with the development of the track laying vehicle. A steam-powered one was first used in the Crimea in 1854.[14] Here it is easy to see how the internal combustion engine facilitated the marriage of form and function. The

[12] "Planning Rural Roads: Mechanisation of construction," Henri Baeyens, 2000

[13] *American Society of Agricultural Engineers, Champion Road Machinery*

[14] IBID

generic term " Caterpillar " was first used in 1909.[15] As you can see, almost 150 years later, the bulldozer still resembles the original bulldozer.



The Scraper was demonstrated the most dramatic change. Fresno scraper was the ancestor of the monsters of today, which can haul 240 cubic. meters per hour over a distance of 100m.[16]

Figure 2-4: Photos of Past and Present Construction Equipment

E. PROBLEM

There are reasons to believe that the Marine Corps needs to re-evaluate current requirements for engineer construction equipment. The Engineer Advocacy Center, Installation and Logistics (I&L) intuitively perceives that Marine Corps Engineers have extra equipment on-hand, given the lack of hours of operation per piece of equipment, a plethora of equipment, and lack of maintainers & operators. The 2nd Force Service Support Group's Engineer Operational Advisory Group concluded in their After-Action Report dated 13 Sept 2001 that there is too much engineer equipment held at the unit

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[15] IBID

[16] IBID

level. To further understand this problem, we must review the recent history impacting the engineer community.

The Marine Corps has witnessed significant changes in its acquisition and force levels over the past twenty years, yet it has not reduced its Table of Equipment (T/E) inventories to match the reduction in the force. T/E's specify the type and amount of each major end-item (equipment, i.e., tanks, bulldozers, F-18s, etc.) a unit must possess and maintain. Engineer unit T/Es have grown over the years due to the introduction of new technologies, lack of disposal plans for aging equipment, and outdated acquisition objectives. It seems that the equipment acquisition strategy in the past has been to purchase as much as possible without looking at the reality of what is actually needed.

Another major contribution to the problem is that the Marine Corps Engineer Community is also using outdated requirement documents with no way to discover the original rationale or methodology used for determining those amounts. Some of the construction equipment requirements were written over 20 years ago. For example, the D-7G, Heavy Crawler Tractor (Bulldozer) was approved on 10 October 1976 but the requirement document has been modified very little since, even though doctrine and missions have changed.

The end of the Cold War has also driven changes to the Marine Corps' focus and operational tempo. The Marine Corps has found itself performing more Military Operations Other Than War (MOOTW) than ever before. These missions include Humanitarian Assistance, Peace Keeping, and Combating Terrorism. Moreover, before the end of the Cold War, America conducted these types of operations/missions in concert with NATO nations from permanent garrisons stationed overseas, which made it easier to have large stocks of equipment on-hand. Today, the focus is on more mobile operations with less overseas permanent garrisons, requiring real time delivery of capital assets. This new change in doctrine is impacting the way the Marine Corps conducts daily business and prepares itself for future missions.

F. IMPACTS

The quantity and age of the equipment being maintained at the individual Marine Expeditionary Forces is causing increasing problems for the maintenance and logistic components of the Fleet Marine Force (FMF). The impacts include:

1. Increased Operations and Maintenance (O&M) costs.

If the USMC is retaining too much equipment, then it is expending precious O&M dollars on maintenance requirements that may not be necessary.

2. Decreased personnel/equipment readiness.

If too much equipment is being maintained, units focus on equipment maintenance, rather than individual training requirements. These results in decreased operational readiness of the individual Marine; negatively impacting the USMC's morale and proficiency.

3. Increased logistics requirements.

An unnecessary maintenance requirement caused by having too much equipment will cause the supply chain to become congested with parts.

With no foreseeable increases to future defense budgets; it will place additional burdens on the Marine Logisticians to ensure that the capital assets are available where and when they are needed. Readiness and utilization will be crucial to meeting the future mission requirements.

III. READINESS AND UTILIZATION ANALYSES, AND DECISION METHODOLOGY

A. READINESS ANALYSIS

Operational readiness is a tremendously important factor in the determination of USMC heavy construction equipment quantities. The common metric for readiness is operational availability (A_O). Operational availability is a measure of the percentage of assets that are available for use, at any random time the assets might be needed. It can similarly be interpreted as the percentage of time that a single piece of equipment can be expected to be operationally capable on demand. For example, if a MEF possesses 50 bulldozers, and an A_O of 80 percent, then the MEF can be expected to have 40 dozers ready for use at any given time. Similarly, a single bulldozer can be expected to be usable for operations on four of any five days. Mathematically, A_O is computed as:

$$A_O = \frac{\text{Uptime}}{\text{Uptime} + \text{Downtime}}$$

If A_O were always 100 percent, the quantity of equipment needed would simply be the number of items necessary to satisfy a known level of demand. For example, assume a battalion must have the available capacity to simultaneously grade 100 miles of road during any randomly selected 10-hour period at 10 different job sites. Further assume that all graders work at the speed of 5 miles per hour. To accomplish the job in the allotted time, the battalion must operate two graders at each site continuously for 10 hours (2 graders x 10 hrs x 5 miles/hr = 100 miles) to accomplish the mission. The overall battalion asset requirement would be 2 graders per site, or 20 graders total– if operational availability were always 100 percent.

In reality, individual pieces of equipment will be rendered unavailable at times due to:

- Scheduled and unscheduled maintenance
- Awaiting maintenance or parts for various reasons, including supply delays or manpower shortages
- Transit to a deployment location
- Other factors

Because these requirements are inevitable and render some assets unusable for varying periods of time, 100 percent A_O cannot be sustained over the long-term, though a well-managed pool of assets, properly supported by a well-designed supply and logistics system can achieve the highest possible level of readiness. Analyzing the data provided by Mr. Carroll[17], MEF's I, II, III, and IV were found to have an average grader operational readiness of 86.3% between 1996 and 2002.

In the grader example, the *inflexible requirement* is for 20 operational graders ready for use at any given time. To allow for proper upkeep and maintenance, and to account for the fact that equipment must sometimes be transported to create mission utility, the battalion must actually possess more than the 20 graders needed for the assigned task. If average A_O is 86.3%, then the actual number of graders required is 20 divided by .863 (A_O), or 24 graders to accomplish the battalion mission.

B. READINESS DATA

With this description of readiness behind us, a summary of the historical A_O data described previously is presented for each of the four primary line items (BTAM's) we analyzed, categorized by BTAM, MEF, and calendar year. All values given were computed by dividing the number of non-deadlined (operationally available) assets by the total number of reported assets on hand for each MEF.[18]

17 Readiness data provided by R. Michael Carroll, GS-12. Supply Chain Management Center, MARCORLOGBASES. Data is based on weekly readiness reports from I, II, III, and IV MEF for the period between 1 Jan 1996 and 31 Dec 2002. It is separated by BTAM (equipment type) and MEF, and differentiates between maintenance, supply, and transportation-deadlined equipment.

18 MCO 3000.11D delineates readiness reporting requirements. Three ratings are used to report readiness. These readiness figures reflect the Equipment Condition, or "R" rating percentages, equal to the number of items on hand minus the number of deadlined items, divided by the number of items on-hand. Other readiness ratings used by the USMC are the Supply, or "S" rating percentage, which reflects the ratio of equipment on hand to the number of equipment pieces authorized. This percentage is often greater than 100. Lastly, Material Readiness "MR" is computed by dividing the number of "up" assets by the authorized unit quantity, rather than the quantity actually possessed by a unit.

YEAR	MEF				OVERALL AVERAGE READINESS
	I	II	III	IV	
1996	81.8	80.4	85.4	94.6	86.00
1997	86.4	86.8	85.1	95.5	89.10
1998	91.2	82.5	87.8	93.0	89.30
1999	88.2	74.0	86.3	93.4	86.20
2000	89.8	85.2	86.1	97.1	90.50
2001	84.6	76.2	77.0	95.9	84.70
2002	76.3	73.6	62.8	90.8	78.10
OVERALL	**85.5**	**79.8**	**81.5**	**94.3**	**86.3**
S.D.	**5.14**	**5.34**	**8.96**	**2.11**	**4.17**
GRADERS ON HAND (AVG)	**22.7**	**19.8**	**12.4**	**25.4**	**80.3**

Table 3-1: B1082 Motorized Road Grader,
Caterpillar 130G A_O Data By Year and MEF

Overall, IV MEF (the reserves) attained the highest level of readiness for all items/BTAMS analyzed in this project. In the case of the 130G Motorized Road Grader, II MEF's readiness was the poorest, especially after 1997. There is a noticeable decrease in readiness for all MEF's after 2000, caused by an increase in the number of items deadlined and in transit as Marines prepared for their roles in the Middle East.

YEAR	MEF				OVERALL AVERAGE READINESS
	I	II	III	IV	
1996	84.5	81.3	76.8	91.7	83.1
1997	76.3	84.3	70.6	87.3	79.9
1998	67.6	57.7	69.4	97.2	71.2
1999	59.6	55.4	66.7	98.4	68.3
2000	75.6	85.2	73.2	97.7	83.6
2001	74.6	76.7	68.5	78.4	75.2
2002	74.4	77.6	67.6	92.5	77.8
OVERALL	**73.2**	**74.0**	**70.4**	**91.9**	**77.0**
S.D.	**7.78**	**12.36**	**3.54**	**7.16**	**5.81**
SCRAPERS ON HAND (AVG	**10.6**	**10.1**	**5.5**	**6.9**	**33.2**

Table 3-2: B1922 Scraper-Tractor, Wheeled,
Caterpillar 621B A_O Data By Year and MEF

Readiness percentages for the 621B Scraper vary widely from year to year, and even week-to-week as evidenced by the relatively high standard deviations listed. This is what MCO 3000.11D terms a "critical low-density piece of ground equipment. Small changes in quantities possessed or equipment condition can lead to wide fluctuations in a unit's sorts (readiness) ratings."[19] These wide variations also likely explain the fact that scrapers achieved the lowest operational availability of the four PEI's between 1996 and 2002. Two trends were identified however. First, there was a noticeable decrease in readiness for MEF's I, II, and III, in 1998 and 1999, before rebounding in 2000. Second, as with the grader, there is a perceivable decrease in operational availability in 2001, leveling again in 2002.

	MEF				**OVERALL AVERAGE**
YEAR	**I**	**II**	**III**	**IV**	**READINESS**
1996	88.0	90.2	94.5	95.3	91.5
1997	88.9	91.4	91.6	94.1	91.3
1998	94.7	83.7	91.9	93.2	90.7
1999	90.0	92.4	99.7	98.1	94.5
2000	93.6	89.8	89.6	92.4	91.6
2001	83.3	84.7	92.2	91.5	87.2
2002	88.6	84.5	87.6	90.3	87.6
OVERALL	**89.6**	**88.1**	**92.4**	**93.6**	**90.6**
S.D.	**3.78**	**3.66**	**3.86**	**2.59**	**2.52**
MC1150 TRACTORS ON HAND (AVG	**31.7**	**31.0**	**18.0**	**25.7**	**106.4**

Table 3-3: B2460 Tractor, Tracked,
MC 1150 A_O Data By Year and MEF

The 1150 tractor exhibited the highest A_O of the four BTAMS for which readiness data was available, with an average near 90 percent over the observed seven-year period. This success is likely attributable to a combination of equipment reliability, maintainability, and supply support. Note though, that there is still a minor aggregate drop in operational availability after 2000.

19 MCO 3000.11D Paragraph 6.b.3, USMC Headquarters, Installations and Logistics, 2003

YEAR	MEF I	II	III	IV	OVERALL AVERAGE READINESS
1996	79.3	84.0	92.3	92.8	85.9
1997	82.4	81.8	90.2	91.9	85.6
1998	75.6	79.2	84.2	91.3	81.2
1999	81.7	82.8	88.8	91.6	85.3
2000	88.0	89.4	86.8	90.2	88.5
2001	85.6	89.3	89.3	95.4	89.1
2002	88.2	88.8	91.9	97.8	90.7
OVERALL	**83.0**	**85.0**	**89.1**	**93.0**	**86.6**
S.D.	**4.64**	**4.12**	**2.85**	**2.67**	**3.14**
D7'S ON HAND (AVG	**63.8**	**54.9**	**41.2**	**33.9**	**193.9**

Table 3-4: B2462 Tractor, Tracked,
Caterpillar D7G Bulldozer A_O Data By Year and MEF

The operational availability of the D7G presents a trend different from the Scraper, Grader, or 1150 Tractor. Like the other items, the reserves have achieved a readiness rate greater than MEF's I, II, or III over the past seven years. Interestingly though, overall D7G dozer operational availability has improved each year since 1998, and note that the overall A_O has increased almost 10 full percentage points, from a low of 81.2% in 1998 to a 2002 level of 90.7%. The most likely cause of this improved readiness is an effective Service Life Extension Program that began in 1997. This program sought to "remanufacture each D7G using original equipment manufacturer (OEM) parts and procedures."[20]

1. Causes of Non-Availability

The data obtained from Material Command[21] breaks down non-mission capable assets into three categories that describe why the equipment is not available. They are as follows:

[20] Heavy Crawler Tractor Required Operational Capability Document, Marine Corps Systems Command, Updated 24 September 2002.

[21] Readiness data provided by Mr. Mike Carroll.

a. ***Maintenance***

Due to maintenance, meaning that the item is deadlined, and is either undergoing scheduled maintenance, unscheduled maintenance due to breakage, or is awaiting maintenance due to work backlog or a shortage of qualified personnel.

b. ***Supply***

Equipment is deadlined because of a lack of parts necessary to restore the equipment to operational status.

c. ***Transportation***

The equipment is unavailable to the readiness-reportable unit because it is in transit between repair activities, or between deployment locations. Table 3-5 lists the percentage of non-operational equipment, separated according to the reason its availability was degraded.

The most common reason for deadlined equipment is supply, followed closely by maintenance. Transportation is a more significant cause of deadlines for the Scraper and D7G Dozer than for Graders or the 1150. In all cases however, the impact of transportation as a readiness degrader can be reduced through more efficient material processing procedures, designed to minimize processing time required to prepare items for shipment, reduce holding times at locations where equipment is transferred between transportation modes, and reducing the time required to prepare equipment for use after shipment. The duration of non-availability due to supply and maintenance delays can be addressed by carefully monitoring and refining the logistics and support system, as well as examining training and manpower allocation among the operational units.

END ITEM	MEF	% MAINTENANCE DL	% SUPPLY DL	% TRANS DL
GRADER/B1082	I	31.9	**54.7**	13.5
	II	**48.5**	45.3	6.3
	III	32.7	**53.0**	14.3
	IV	30.5	**55.9**	13.6
	ALL	37.9	**51.0**	11.0
SCRAPER/B1922	I	35.2	**42.3**	22.5
	II	**45.9**	38.0	16.1
	III	27.6	**46.2**	26.2
	IV	32.3	30.7	**37.0**
	ALL	37.1	**40.8**	22.1
MC 1150/B2460	I	30.4	**54.4**	15.1
	II	**53.9**	36.2	9.9
	III	36.9	**58.1**	5.0
	IV	38.9	**53.9**	7.2
	ALL	41.4	**48.1**	10.5
D7G DOZER	I	**39.8**	35.9	24.3
	II	**47.0**	36.0	17.0
	III	41.5	**44.1**	14.4
	IV	27.5	**36.5**	36.0
	ALL	**41.2**	37.4	21.4
ALL BTAMS	I	34.3	**46.8**	18.8
	II	**48.8**	38.9	12.3
	III	34.7	**50.4**	15.0
	IV	32.3	**44.3**	23.5
	ALL	**39.4**	**44.3**	**16.2**

Table 3-5: Reason For Equipment Non-Availability

C. APPLICATION OF READINESS DATA TO CAPACITY DETERMINATION

Similar to the example of determining the required number of graders, if the total capacity demand were known for an entire MEF, or for the entire Marine Corps, it would be possible to determine actual construction equipment quantities necessary to accomplish basic missions plus any anticipated operational surges. Put another way, the pool of available construction equipment resources could be "right-sized" to exactly meet anticipated demand.

As explained earlier, it is necessary to make allowances for less-than-perfect operational availability. If A_O can be predicted or quantified with some degree of certainty and confidence, it is then possible to determine the necessary level of "safety stock", or additional equipment quantity needed to fulfill the mission while properly performing maintenance and upkeep, as well as permitting the transportation of equipment to worldwide locations where it may be needed.

Continued trend analysis and tracking of readiness is absolutely essential for maintaining the proper amount of equipment. The more stable and constant operational availability can be maintained, the greater the level of precision possible in determining final authorized equipment levels among MEF's. The computer capacity forecasting models developed in this project incorporate the actual data from 1996-2002, using statistical distributions to describe the readiness history of each BTAM for each MEF. Specifics are saved for the Capacity Analysis and Model Description portion of this report, which describe the models and their governing assumptions in detail.

D. UTILIZATION ANALYSIS

Another important element of overall capacity quantification is utilization. Modifying the referenced definition slightly, utilization is described as "the ratio of the number of equipment items busy to the total number of assets available."[22] It is a metric that changes over time, depending on how many assets are actually in use. Alternatively, utilization can also be described as the ratio of processing time (the amount of time an asset is actually in use) to the total amount of time available.[23] Using D7G bulldozers as an example, assume that a MEF has 25 bulldozers. Further, now assume that the number of bulldozers actually in use changes from hour to hour for an eight-hour workday as noted in the table below. Hourly and average daily utilization rates for this example are given in the right-hand column of Table 3-6.

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[22] Kelton W.D., Sadowski R.P, and Sadowski D.A.; Pg.131; *Simulation With Arena: Second Edition*. McGraw Hill, New York, 2002.

[23] Gue, Kevin R., Naval Postgraduate School Professor of Operations Management, Interview, 8 May 2003.

Time Beginning	Equipment Hours Available	Equipment Hours Used	Utilization Rate (%)
0800	25 x 1 = 25	5 x 1 = 5	20%
0900	25	10 x 1= 10	40%
1000	25	15	60%
1100	25	15	60%
1200	25	10	40%
1300	25	10	40%
1400	25	10	40%
1500	25	5	20%
Daily Average Utilization	**= 25 x 8 = 200**	**80**	**= 80/200 = 10/25 = 40%**

Table 3-6: Hypothetical Hourly Usage Table to Illustrate Utilization Calculation

Utilization is a measure of how efficiently resources are employed by those who manage them. In a situation where demand for equipment perfectly matched the number of equipment-hours available for construction tasks, utilization would be 100%, with human and material resources in use at all times. Anything less than 100 percent utilization implies that excess capacity is available in the system. Excess capacity translates into manpower and money that could be expended elsewhere. In the case of military heavy construction equipment, idle resources not only represent monetary investment in capital assets, but also demand the expenditure of time, money, and manpower to maintain unused equipment in operational condition. The following anecdote, as stated by Caterpillar's Supervisor of Custom Machine Development-Marketing & Contract Administration within their Defense & Federal Products Division illustrates this point quite well.

> In general, the military's problems are centered around deterioration rather than wear and tear as we see with our commercial customers. A good example is your scrapers. I was at Ft Picket, VA last year where the 82nd Airborne Division was reworking the airfield there. They had signed out a half dozen 621B scrapers from the reserve unit at Picket. All of them were deadlined for cylinder leaks within the first week of operation. The young Commander on the ground couldn't understand why this was so.....I explained to him the fact that scrapers need to be exercised regularly for good maintenance.... not simply started allowing the engine to run for a few minutes. He pointed out that it was next to impossible to get the kind

of missions necessary to utilize a scraper. After 20 years in the Army Engineers, I can attest to this..... unfortunately, it still needs to be done OR expect those type of failures to occur.[24]

One key decision for military leaders is how to optimally balance the quantities of equipment on hand such that A_O is maximized. With too much equipment, the situation described by Mr. Sharp occurs, and idle equipment degrades due to under-utilization. With too little, the consequences are overused equipment, and potentially insufficient quantities to meet "peak wartime usage" in contingencies. Graphically, this decision can be represented as shown in Figure 3-1.[25]

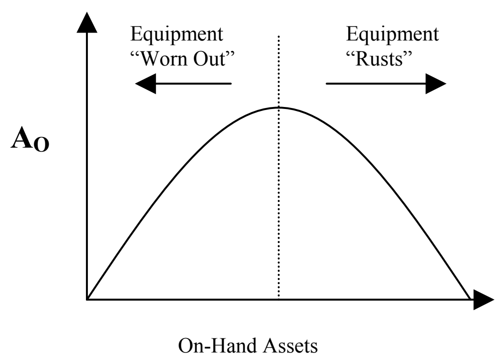

Figure 3-1: Notional Dependence of A_O on On-Hand Equipment Quantity

Additionally, extra space is required to store extra items, and they demand additional administrative time and effort in terms of tracking, transportation, and life cycle management.

E. UTILIZATION DATA

One of the more frustrating aspects of our research has been the absence of reliable data to quantify the utilization of Marine Corps heavy construction equipment. The initial set of data received from Mr. Mike Carroll (not the previously referenced readiness data) listed maintenance inductions by serial number as recorded on Equipment Repair Order (ERO) requests. ERO's are essentially work request forms that document

[24] Sharp, Richard E.; Supervisor, Custom Machine Development-Marketing & Contract Administration, Caterpillar, Defense & Federal Products Division. Interview, 21 April 2003

[25] Franck, Raymond, Ph.D. Naval Postgraduate School Senior Lecturer, Graduate School of Business and Public Policy, Project Advisor; Interview 16 May 2003.

equipment induction and maintenance completion dates, as well as maintenance labor hours expended, equipment meter readings, and equipment operating time codes that specify what is measured by the indicated meter reading (hours, days, miles, etc.) A random sample of the historical ERO data provided for three different S/N D7G bulldozers from II MEF is shown in Table 3-7.

TAM CTL NR	NATIONAL STOCK NUMBER	SERIAL NUMBER	METER READING	EQUIP OPER TM CD	ERO NR	DATE IN SHOP	DATE CLOSED	LABOR HRS	MEF
B2462	2410-01-155-1588	522128	0	H	E5804	02162	02177	3.0	II
B2462	2410-01-155-1588	522130	1	H	AP435	00011	00194	0.1	II
B2462	2410-01-155-1588	522130	0	H	F0852	00174	00193	0.0	II
B2462	2410-01-155-1588	522130	700	H	F0853	00174	00193	4.0	II
B2462	2410-01-155-1588	522130	0	H	F1784	00207	00243	0.0	II
B2462	2410-01-155-1588	522130	818	H	F1785	00207	00230	1.0	II
B2462	2410-01-155-1588	522130	0	H	F9558	00342	00363	0.0	II
B2462	2410-01-155-1588	522130	0	H	F9559	00342	00363	4.0	II
B2462	2410-01-155-1588	522130	1239	H	FG663	01311	01324	1.0	II
B2462	2410-01-155-1588	522130	0	H	FJ287	02008	02009	0.0	II
B2462	2410-01-155-1588	522130	1274	H	FJ288	02008	02009	1.0	II
B2462	2410-01-155-1588	522130	0	H	FJ510	02011	02022	0.0	II
B2462	2410-01-155-1588	522130	1274	H	FJ511	02011	02014	3.0	II
B2462	2410-01-155-1588	522130	1337	D	FC5S2	02224	02239	1.0	II
B2462	2410-01-155-1588	522130	456	H	AP437	99286	99291	3.0	II
B2462	2410-01-155-1588	522130	499	H	AP438	99288	99357	6.0	II
B2462	2410-01-155-1588	522131	0	H	F1731	00206	00222	0.0	II
B2462	2410-01-155-1588	522131	234	H	F1732	00206	00217	1.0	II
B2462	2410-01-155-1588	522131	0	H	FMH78	01268	01268	0.0	II
B2462	2410-01-155-1588	522131	0	H	FMH79	01268	01268	4.2	II
B2462	2410-01-155-1588	522131	484	H	FF989	01288	01332	7.0	II
B2462	2410-01-155-1588	522131	484	H	FG664	01311	01332	6.0	II
B2462	2410-01-155-1588	522131	0	H	FM555	02077	02078	0.0	II
B2462	2410-01-155-1588	522131	499	H	FM556	02077	02078	6.0	II
B2462	2410-01-155-1588	522131	0	H	FP417	02129	02137	0.0	II
B2462	2410-01-155-1588	522131	499	H	FP418	02129	02136	1.0	II
B2462	2410-01-155-1588	522131	0	H	FP744	02140	02164	0.0	II
B2462	2410-01-155-1588	522131	499	H	FP745	02140	02158	0.5	II

Table 3-7: Sample of Provided D7G ERO Maintenance Data

It would seem that the meter-reading field would provide a starting point for determining average equipment utilization in terms of average operating hours per day, month, or year. However, note all of the zeros in the Meter Reading field. For a relative few of the serialized line items, it is possible to make some chronological sense of the meter readings, but only after making assumptions about the validity of the data. For example, a listed meter reading of four hours makes no sense if listed as a 4, but would seem logical if it had read 40 hours instead. After much frustration trying to make sense of the given data, we came to the same conclusion as Mr. Mike Carroll of USMC Materiel Command:

> Failure rates should be measured in relation to equipment usage. The only MIMMS field available for determining equipment usage is METER-READING. This field is supposed to contain the meter reading at the time of the maintenance action. This field has proven to be extremely unreliable, and our attempts to use it have been frustrating to say the least. We have attempted to identify and weed out the obviously bad entries like all nines and all sixes, but were still unable to make any sense out of the readings. The meter readings have been useless in our efforts. The problem is compounded when you consider other data problems (i.e. The Serial Number field is inconsistent). I know that Capt Jake Enholm (MATCOM) performed an analysis of the integrity of several MIMMS fields. Here is his conclusion on the Meter Reading field: The MIMMS data fields: Meter Readings, and Civilian Labor Charge from D0209 vehicles from 1998-2001 should not be used in any sort of analysis. Any MIMMs data from other equipment during the same time frame should also be similarly screened for analysis use. The Date Received in Shop field could be used for mean time between failure calculation if the Serial Number field is verified with actual equipment tables. Current MIMMS archiving and data storage techniques do not allow for the easy acquisition of a part number (NSN) to attach to a particular ERO and serial number.[26]

For the sake of argument, let's assume the assumptions made for a few D7G's are valid, and that it is in fact possible to roughly determine the average daily equipment utilization. Table 3-8 provides a summary of D7G sample data for three different serial numbers as follows:

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[26] Carroll, Mike, e-mail dated 5 March 2003 which accompanied the described ERO data.

S/N	Julian Date	METER HRS	HOURS	DAYS	DAILY USAGE (HRS/DAY)
522130	99286	456	881	1049	0.84
	99357	499			
	00193	700			
	00230	818			
	01324	1239			
	02008	1274			
	02239	1337			
522131	00206	234	265	683	0.39
	01332	484			
	02078	499			
	02158	499			
522159	00123	21	74	850	0.09
	00229	40			
	01092	50			
	01093	53			
	01179	54			
	02242	95			

Table 3-8: ERO Data Summary

Daily usage rates were determined by first obtaining the number of operating hours, often requiring assumptions with respect to data input errors (for instance, the 40 hours listed for S/N 522159 is actually a 4 in the provided data). Next, the number of days during which those operating hours were incurred was determined by subtracting the earliest date given from the latest date available in the data. Notice that the average hourly utilization ranges here from less than six minutes per day to 50 minutes per day. These numbers are extremely low, and represent a tremendously low utilization rate.

The additional monetary and opportunity costs of poor utilization have been addressed. In short, equipment that is not in use represents a cost to the Marine Corps without a reciprocal return on their investment in equipment and manpower. One of the first steps toward minimizing idle/excess capacity for the Marine Corps is to quantify current utilization levels for each BTAM equipment type. This determination can be very straightforward, and non-laborious. The fact is that any systematic approach to tracking utilization rates will represent an improvement over the current lack of reliable utilization data.

F. DETERMINING CURRENT UTILIZATION

Mathematically, utilization (ρ) is defined as:[27]

$$\rho = \frac{T_p}{T}$$

T_p = Processing/production time

T = Total time available (Length of workday)

The key metric in identifying utilization is *the number of hours per unit time (day/month/year) that an individual serial number item is used*. In the above equation, this value is represented by the variable T_p. The length of the workday (T) obviously varies greatly in military units, depending on a unit's stage in the training cycle, deployment requirements, and other factors. In the interest of maintaining a simplistic metric for utilization, it is not desirable or even necessary to account for the wide variance of total time available (T) among all MEF's. Rather, it is expected that clearly evident trends will become identifiable as equipment operating rate histories are documented. With minimal analysis, differences in operating rates over time can be directly correlated to unit mobilizations, the numbers of assets available to the unit (e.g., fewer graders available to a unit will translate into higher utilization rates for those assets still on hand), and other asset management decisions.

Our recommendation is relatively simple to implement given that, as required by MCO 4790.7, "each MIMMS AIS-managed equipment (item) will have a designated meter which will indicate the EOT (equipment operating time) of the equipment. A meter reading is always associated to serialized equipment."[28] Our recommendation is

[27] Gue, Kevin R., Naval Postgraduate School, Professor of Operations Management, Interview; 8 May 2003.

[28] MCO 4790.7, Marine Corps Integrated Maintenance Management System Automated Information System, Headquarters Maintenance Subsystem; Appendix C, Data Elements, Pg. B-13.

that units that operate and maintain construction equipment be required to report equipment meter readings for each individual piece of equipment simultaneously with the readiness data required by MCO 3000.11D. By requiring EOT to be reported along with readiness on a weekly or otherwise recurring basis, rather than "at the time the equipment was inducted into the maintenance cycle"[29], HQMC will be able to develop reliable utilization data that is vital to effective asset management. Among the benefits to be gained by requiring weekly operating hours to be reported are:

Measurement of equipment utilization for overall MEF or USMC capacity determination.

Precise usage data that is sortable by unit/MEF, BTAM/equipment type, and individual piece of equipment.

Total equipment hours can be compared to equipment material condition and frequency of unscheduled breakdowns, permitting data-rich, informed choices with respect to equipment retirement and other life cycle decisions.

Though its development is not our expertise, an optimal solution would be to merge the readiness reporting and usage rate data with the maintenance repair database from USMC Material Command. The resultant decision support system would prove very robust in its ability to fully describe the efficiency with which USMC heavy construction equipment is employed.

G. IMPORTANCE OF UTILIZATION IN DETERMINING REQUIRED CAPACITY

As we will detail in the next section of our report, Excel spreadsheet-based forecasting models have been developed for the D7G Bulldozer, D6 (MC 1150) Bulldozer, 621G Scraper, and 130G Road Grader. Given some specifics about the jobs on which the equipment is used, these models compute hourly production rates for each of these equipment types. Assuming the hourly production rate for individual pieces of gear can be predicted with some certainty, the next step in finding overall capacity is to multiply this hourly capacity by the total number of non-deadlined, mission capable

29 Ibid

assets, which then yields the hourly capacity available to the MEF, or even the Marine Corps as a whole. Finally, the MEF or USMC hourly capacities, which are based on numerous job-dependent factors, are multiplied by the equipments' average utilization rates (hours per day) to yield the total available daily capacity. Note in the models that hourly production rates are all multiplied directly by the average daily utilization to obtain available capacity, making utilization the single-most important factor in this analysis.

H. DEMAND PLANNING AND DECISION METHODOLOGY

Once the actual available capacity has been determined based upon the models, it will then be necessary to compare the available capability (identified using the models developed by this project) to the capacity required to support the mission of the Marine Corps. The process of quantifying this required capacity could be thought of as *demand planning*. As a concept borrowed from the discipline of supply chain management, but also germane to this study, "effective demand planning enables a business to optimize the utilization of manufacturing assets, reduce finished goods inventory, and improve customer satisfaction."[30] Demand planning is required in order to make informed decisions about the number of equipment items that can be released from the USMC inventory, or to identify the need for additional required items.

The more precisely future required demand for heavy construction equipment can be defined, the more confident managers can be that inventory decisions will not adversely impact the Marine Corps' ability to meet all future mission requirements. Suggestions for more precise demand planning are given in the descriptions of each model, with the goal of each recommendation being the reduction in variability that surrounds many of the assumptions that must be made to arrive at estimates of available and required capacities.

Using the comparison of available capacity to the needed capacity as determined through demand planning, headquarters, marine corps will then be well-equipped to make informed decisions regarding the "right" quantities of gear to maintain within each mef.

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30 Demand: Demand Planning; www.prescientsystems.com/solutions/demand_plan.html

Where excess capacity exists, the decision is left to HQMC as to the degree of asset reduction that is prudent. The factors to consider are the level of risk that is acceptable when the probability of contingencies is weighed against the benefits of maintaining less construction equipment in the USMC inventory. Some margin of safety or excess capability is desirable to meet anticipated high-intensity demands. However, greater risk may prove acceptable when considered vis-à-vis contingency contracting options such as leasing in overseas operational theaters, or to satisfy surge requirements that emerge from training exercises and other evolutions. Conversely, shortfalls in current AAO quantities may be identified, and the same risk analysis methodology should be implemented to specify new AAO objectives.

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IV. CAPACITY ESTIMATION METHODOLOGY AND MODEL DESCRIPTION

A. OVERVIEW

This chapter describes the spreadsheet tools developed in this project that can be used to more precisely quantify the capacity currently available to the Marine Corps for bulldozing, grading, and scraping operations. The methodology and origin of each model is given, including a description of the initial assumptions made in the models. Finally, as alluded to earlier in the discussion of demand planning, we present ideas for training and task documentation that will narrow the broad range of possible daily capacity outcomes, making the forecasted values closer to reality by reducing much of the uncertainty surrounding the initial assumptions. For each of the three equipment models, (bulldozer, grader, and scraper) three files are provided.

1. A file that summarizes the contents of each cell used to compute capacity. (A cell-by-cell guide).

2. An Excel file that allows the user to analyze discrete scenarios in a what-if fashion to assess the impact of management decisions on available production capacity. This file can also be used as a planning and estimating tool for very specific task scenarios to determine the number of machines, or time required to complete a known job. Its disadvantage is that is does not account for the variance that is inevitable when considering the many different environments, terrain conditions, operational readiness fluctuations, and operator skill levels, as well as numerous other factors that these equipment items should be expected to encounter throughout their service life.

3. The Crystal Ball, Excel-based forecasting model is identical to the Excel file described above, but is designed to provide forecasting ability to the user through Monte Carlo simulation techniques for qualitative risk analysis. "It allows the analyst to assign probability distributions to all uncertain components of a mathematical model of the problem and then, through random sampling of these distributions, determine the

distribution of all potential outcomes that could occur under these uncertainties."[31] By making informed assumptions about the variations among job sites, as well as manpower and equipment utilization management, the models will provide valuable decision making information, especially with respect to upper and lower bounds of expected capacity for each piece of equipment. The potential impacts of management decisions can be assessed in a virtual environment, permitting increased confidence and well-founded justification for the actual implementation of such decisions.

Four governing "forecasting commandments" should be kept in mind while using the provided models, as detailed in the following article:

> The forecast is ALWAYS wrong! ...and that's okay. Therefore, the goal is to effectively manage the forecasting process and combine it with business knowledge to increase accuracy. By lowering the error found in a forecast, the risk of taking on that forecast is minimized. It's how you plan for the forecasted numbers that's important, not the numbers themselves.
>
> People own and manage assumptions, not the forecast. A forecast is a range of information that can help foster a risk-management process. Plan according to that range; understand what resources are necessary for manufacturing 100 items versus 850 items. Build a risk-management process. Accountability should happen at the business-knowledge level, not at the actual-forecast level. Everyone involved must own their numbers, and be evaluated according to their inputs.
>
> Improvement, not perfection. Focus on the level of improvement you experience, not the actual level of accuracy achieved. Again, there is no such thing as a perfect forecast. When looking at the forecasting process, examine all of the different pieces that can be improved on: amount or type of history used, forecasting methods, stakeholders involved in the process, or how the forecast is used for planning. Each step taken to improve the process will result in extraordinary progress in business performance.
>
> Consensus must/will take place. The forecast is not complete until everyone agrees that the same set of assumptions can be executed. Is the lead-time for production reasonable? Does your warehouse have room for your forecasted inventory level? You need the buy-in of everyone

[31] Vose, David (1996), Molak Vlasta (Ed.); Pg.45; "Monte Carlo Risk Analysis and Modeling", *Fundamentals of Risk Analysis and Risk Management*, Lewis Publishers, Inc., Boca Raton, FL

involved in the process to ensure the forecasted numbers are reasonable in all aspects of the business. [32]

B. SOURCE OF MODELS

Each model was generated using the production estimation equations and basic performance data presented in the Caterpillar® Performance Handbook, Edition 31 (2001).[33] This is a logical approach, and the most reasonable for estimating production, since the bulldozers (D7G), graders (130G/140G), and scrapers (621B) used by the USMC are made by Caterpillar, or in the case of the MC 1150 Required Operational Capability (ROC document, the Caterpillar D6C is listed as a suitable substitute.[34] In addition to the pure production equations for each BTAM, the models incorporate Marine Corps-specific management factors that affect production rates, such as equipment utilization, operational availability/readiness (A_O), available manpower, and manpower allocation. To describe the models, first the elements common to all four will be detailed, followed by a synopsis of the components unique to each. Throughout these descriptions, we will describe the Caterpillar® productivity equations used to estimate machine capacity, as well as the assumptions we made for the forecasting model. We will also suggest steps that should be taken to make the assumptions (which are currently very broad because data is severely lacking) much tighter, leading to increasingly precise forecasts of capacity as more empirical data is incorporated to support the decision making process.

[32] Omrod, Anne, John Galt Solutions, June Web Columns. *The Forecasting Commandments*, www.startmag.com/webcolumns/020601.asp.

[33] Caterpillar Inc. (2000), Caterpillar® Performance Handbook, Edition 31, Peoria, IL; Disclaimer: "Performance information in this booklet is intended for estimating purposes only. Because of the many variables peculiar to individual jobs (including material characteristics, operator efficiency, underfoot conditions, altitude, etc.), neither Caterpillar Inc. nor its dealers warrant that the machines described will perform as estimated."

[34] USMC Required Operational Capability documents for Light Crawler Tractor (updated 07/06/99 by Tracey L. Chewning), Heavy Crawler Tractor (updated 09/04/2002 by S. Booth), and Heavy Motorized Road Grader w/Change 1 (updated 07/06/99 by Tracey L. Chewning)

C. ELEMENTS COMMON TO ALL MODELS: DESCRIPTIONS, ASSUMPTIONS AND RECOMMENDATIONS

1. Utilization

Utilization has been addressed earlier in this presentation, but it is important to note again that all daily capacity forecast estimates are ***highly dependant*** upon the projected or historically observed utilization rates.

2. Total (Type of Equipment) Items On-Hand

The annual average quantities on-hand for each MEF (by BTAM) were determined from the readiness data provided. Figures 4-1 through 4-4 show the changes in quantities over the past seven years. Contrary to our expectations, the aggregated quantities maintained by the MEF's have not changed dramatically, though there are variations between individual MEF's, and BTAM's. In particular, scraper quantities range between 30 and 35, which is a range of just over 5 pieces of equipment, or just over one scraper per MEF over seven years. The small total quantity makes this variation look substantial, yet the 2002 average quantity of 35.6 scrapers is only marginally higher than the 1996 quantity of 24.8.

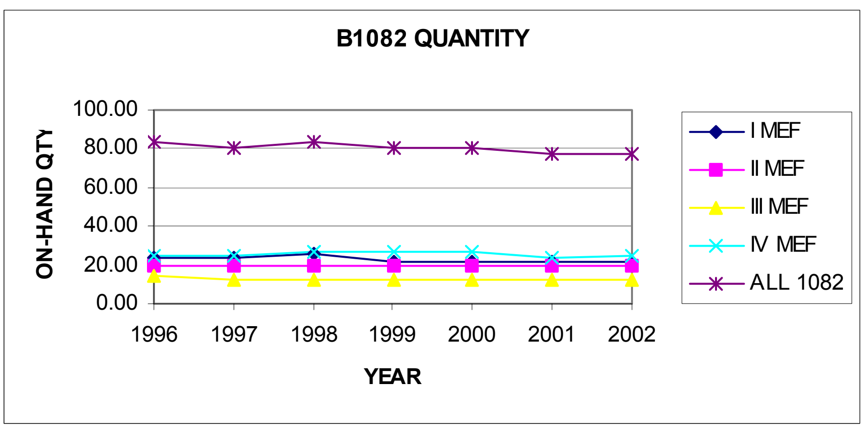

Figure 4-1: Graders On Hand By Year; 1996-2002

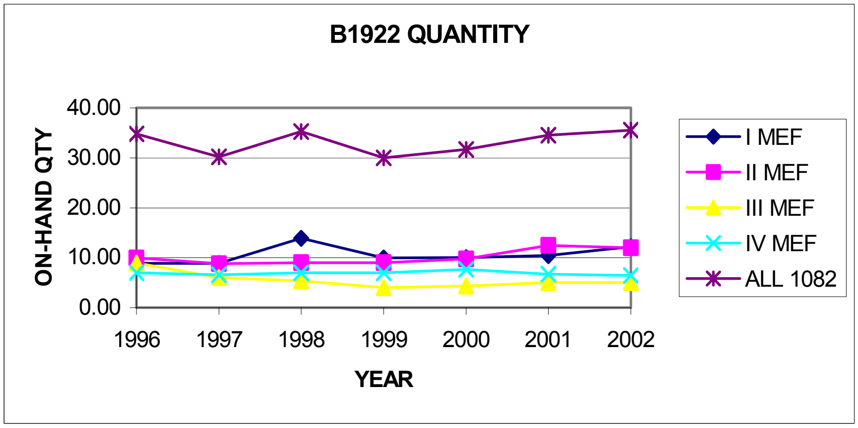

Figure 4-2: Scrapers On Hand By Year; 1996-2002

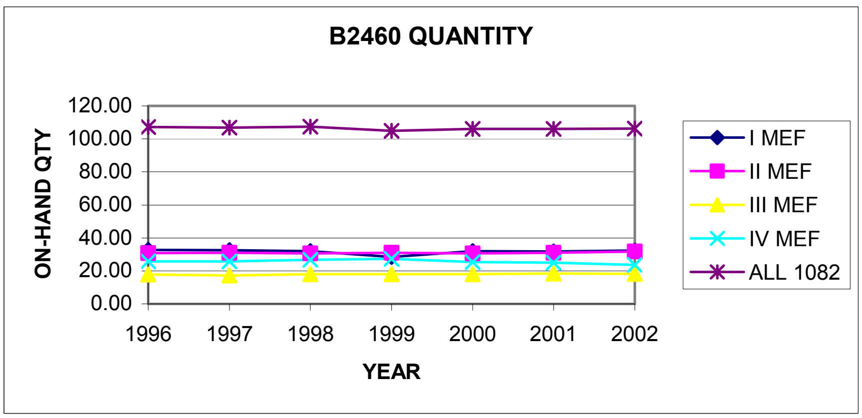

Figure 4-3: MC 1150s On Hand By Year; 1996-2002

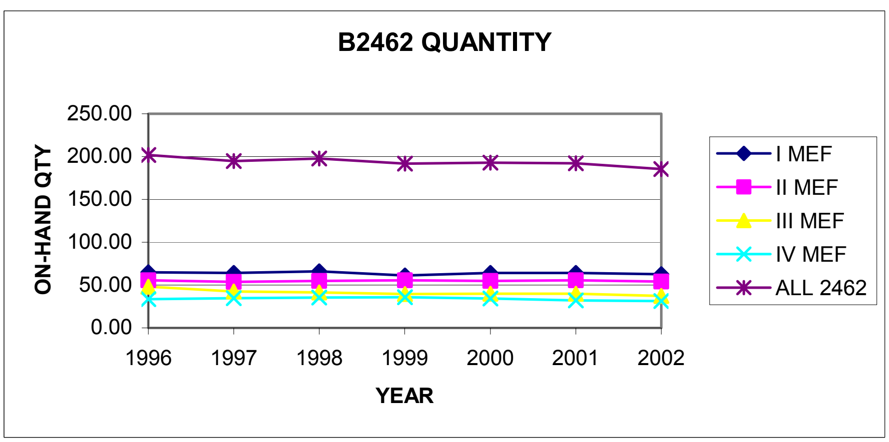

Figure 4-4: D7G Bulldozers On Hand By Year; 1996-2002

For capacity forecasting purposes, normal distributions were incorporated into the Crystal Ball models to account for the annual variance in on-hand equipment quantities.

Recommendations: Continue to track on-hand equipment quantities, as well as the quantities of excess equipment stored remotely in places such as Barstow, CA and Albany, GA. Desired AAO objectives can easily be plugged into the models and tested for their impact on mission effectiveness, once other model parameters have been more specifically defined.

3. Operational Availability (A_O)

The year-by-year readiness averages by BTAM and MEF were presented previously. To provide a more robust depiction of reality for the model, data analysis techniques were used to incorporate all reported weekly readiness data over the period from 1996 and 2002 for each BTAM. The Input Analyzer tool, which "accompanies Arena®[35], is designed specifically to fit distributions to observed data, provide estimates of their parameters, and measure how well they fit the data."[36] The weekly A_O figures were saved in an ASCII text file, and the Input Analyzer tool was used to "fit" the most appropriate statistical distribution to the available data. An example of the tool's output is provided below, and in this specific case, represents the readiness data for the D7G bulldozer as reported by I MEF over a seven-year period. The histogram is a plot of the actual frequency of occurrence for readiness values within the bin range. For example, Table 4-1 details the histogram (Figure 4-5) for the I MEF D7G data.

[35] Arena® is a discrete-event simulation software package. www.arenasimulation.com, May 14, 2003.

[36] Kelton W.D., Sadowski R.P, and Sadowski D.A.; Pg.147; *Simulation with Arena: Second Edition*. McGraw Hill, New York, 2002.

Bin	Frequency	Cumulative %
65%	1	.3%
66%	0	.3%
68%	0	.3%
70%	6	2.0%
72%	14	5.9%
74%	9	8.5%
75%	14	12.4%
77%	33	21.7%
79%	20	27.3%
81%	25	34.4%
83%	26	41.7%
84%	29	49.9%
86%	57	65.9%
88%	41	77.5%
90%	37	87.9%
92%	19	93.2%
93%	12	96.6%
95%	5	98.0%
More	7	100.0%

Table 4-1: Frequency of I MEF D7G Weekly Operational Readiness Values

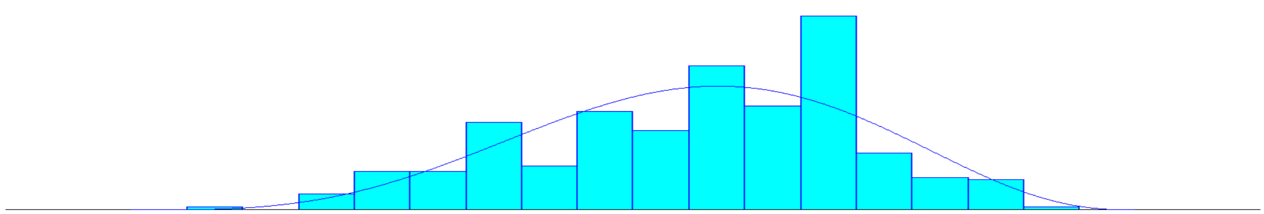

Figure 4-5: Histogram of I MEF D7G Operational Readiness Values

Input Analyzer assesses the closeness of the data fit, and the relative quality of one distribution's fit over others can also be determined, as shown below. The "best" fit is chosen by Arena as the one that minimizes the square error, or difference between the fitted probability function values for each value within the expected range, and then actually observed values. "The larger this square error value, the further away the fitted distribution is away from the actual data (and thus the poorer the fit)."[37]

Distribution Summary

Distribution: Beta
Expression: 0.61 + 0.39 * BETA(4.72, 3.65)
Square Error: 0.014953

Chi Square Test
Number of intervals = 12
Degrees of freedom = 9
Test Statistic = 54.5
Corresponding p-value < 0.005

Kolmogorov-Smirnov Test
Test Statistic = 0.086
Corresponding p-value < 0.01

Data Summary

Number of Data Points = 355
Min Data Value = 0.646
Max Data Value = 0.969
Sample Mean = 0.83
Sample Std Dev = 0.0632

Histogram Summary
Histogram Range = 0.61 to 1
Number of Intervals = 18

Fit All Summary

Function	Sq Error
Beta	0.015
Weibull	0.0154
Normal	0.0172
Triangular	0.0183
Gamma	0.0236
Erlang	0.0236
Lognormal	0.0279
Uniform	0.0543
Exponential	0.0819

[37] Ibid, Pg. 150

The Beta distribution provides the lowest square error in this case, thus represents the best fit among the available distributions for this particular set of data. However, the Beta distribution is complex, and the marginal gain it provides for the model does not warrant the necessary mathematical computations or effort needed to provide future model flexibility. For each BTAM and MEF, when a complex distribution emerged as the "best fit", a simple distribution was always am appropriate substitute. Given the limited data available, the most prudent distributions to use are also the simplest to develop. The normal, triangular, and uniform distributions should effectively account for the inherent variability for all elements of these capacity estimation problems. Once the distributions are derived by Input Analyzer, or estimated by qualified personnel, they can be input directly into the Crystal Ball models, using the CELL: DEFINE ASSUMPTION dialogue box. The characteristics of the three distributions are given below:

a. Normal Distribution

Given in the form; NORM (0.83, 0.0631)

0.83 = Mean (average) value of all data

0.631 = Standard Deviation

The mean and standard deviations are easily computed using the AVERAGE and STDEV functions (respectively) in Excel®.

The normal distribution is symmetric about its mean, and the standard deviation measures how widely spread out the results can be. In the D7G example given here, the probability of a weekly readiness value being between plus or minus one standard deviation is 68.3. The probability of being within two standard deviations is 95.5%, and within three, 99.7 %. Using 83% as the mean, and 6.31% for standard deviation, the likelihood of readiness for any given week being within the shown ranges is:

Probability	Variation	Computation	Range of Outcomes
68.3%	± 1 S.D.	83% ± (1)*6.31%	76.7 - 89.31%
95.5%	± 2 S.D.	83% ± (2)*6.31%	70.4 – 95.62%
99.7%	± 3 S.D.	83% ± (3)*6.31%	64.1 – 100%*

* - The upper limit of A_O is 100%, thus the model assumes all values ≥ 100% = 100%

b. Triangular Distribution

Given in the form; TRIA (.30, .786, 1)

The first number represents the lower bound, the middle number the most likely outcome, and the third number represents the upper bound (1 represents 100% operational availability).

"The triangular distribution is used in situations in which the exact form of the distribution is not known, but estimates (or guesses) for the minimum, maximum, and most likely values are available. The triangular distribution is easier to use and explain than other distributions that may be used."[38]

c. Uniform Distribution

The uniform distribution is used when a minimum and maximum value are know, and all values in-between are equally likely. Consider a six-sided die. The distribution of possible outcomes is: UNIFORM (1,6), since each value has a 1/6 probability of occurring A summary of the fitted A_O distribution expressions for all BTAMS and MEF's is given in Table 4-2.

[38] Ibid, Pg. 596

EQUIPMENT TYPE		
MEF	**D7G Bulldozer**	**Grader**
I	NORM (0.83, 0.0631)	NORM (0.854, 0.0867)
II	NORM (0.851, 0.0595)	NORM (0.797, 0.108)
III	NORM (0.891, 0.0551)	NORM (0.814, 0.136)
IV	NORM (0.93, 0.052)	NORM (0.944, 0.0379)
EQUIPMENT TYPE		
MEF	**Scraper**	**D6 Bulldozer**
I	NORM (0.73, 0.179)	NORM (0.896, 0.0723)
II	NORM (0.74, 0.182)	TRIA (0.67, 0.936, 1)
III	NORM (0.704, 0.171)	NORM (0.925, 0.059)
IV	NORM (0.92, 0.127)	TRIA (0.82, 0.965, 1)

Table 4-2: Initial A_O Distributions Incorporated into Crystal Ball Model

Recommendation: Readiness data was the easiest of all required data to obtain for our analysis, because of the assistance of USMC Material Command, and the weekly readiness reporting that is required by MCO 3000.11D. In order to maintain the viability of the models, it is important to recognize the dynamic nature of operational readiness. The operational availability distributions will need to be updated periodically in order to reflect trends and projections for the future (based on the positive impacts of SLEP or other programs, or the impacts of maintenance, supply, or transportation issues on readiness).

4. Operator/Equipment Ratio

One of the assertions made as we commenced this project was that manpower had been decreased without a corresponding change in equipment quantities. To test this assertion, the number of mechanics and operators per piece of equipment were computed by MEF, and by year. It was difficult to determine the actual quantity of equipment in hand at each MEF, apart from using the same on-hand quantity numbers that were embedded within the readiness data. Figures 4-6 though 4-9 show how the ratios of operators (MOS 1345) to equipment quantities on hand for each BTAM have changed since 1996, per the readiness data provided. The number of mechanics and operators is the same for all four BTAM's within the same year. The reason is that all operators and maintenance technicians are employed as a resource pool, not specifically limited to operating or repairing only one type of equipment.

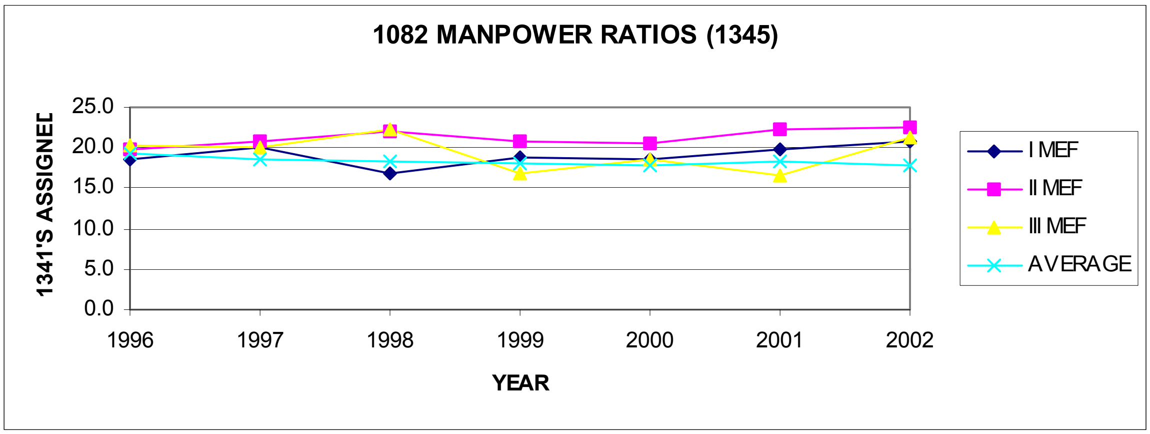

Figure 4-6: Grader Ratios

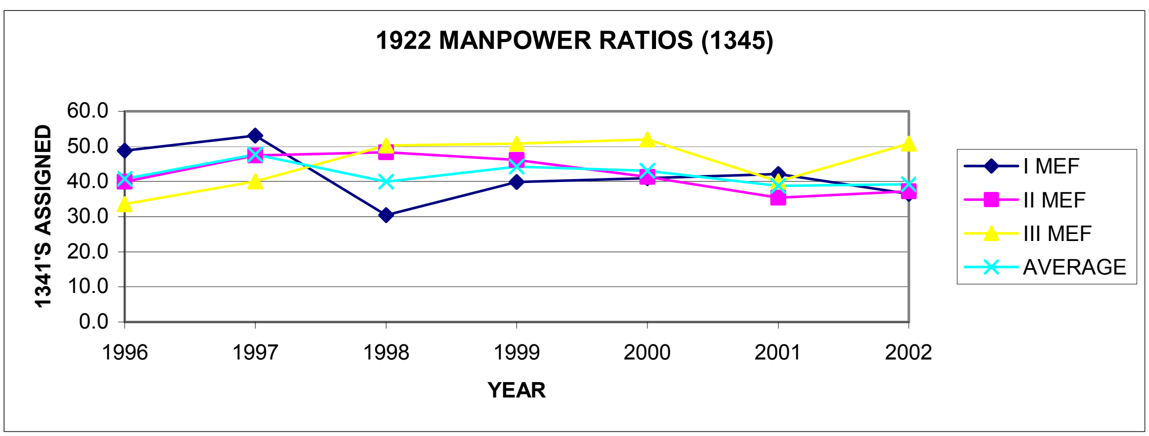

Figure 4-7: Scraper Ratios

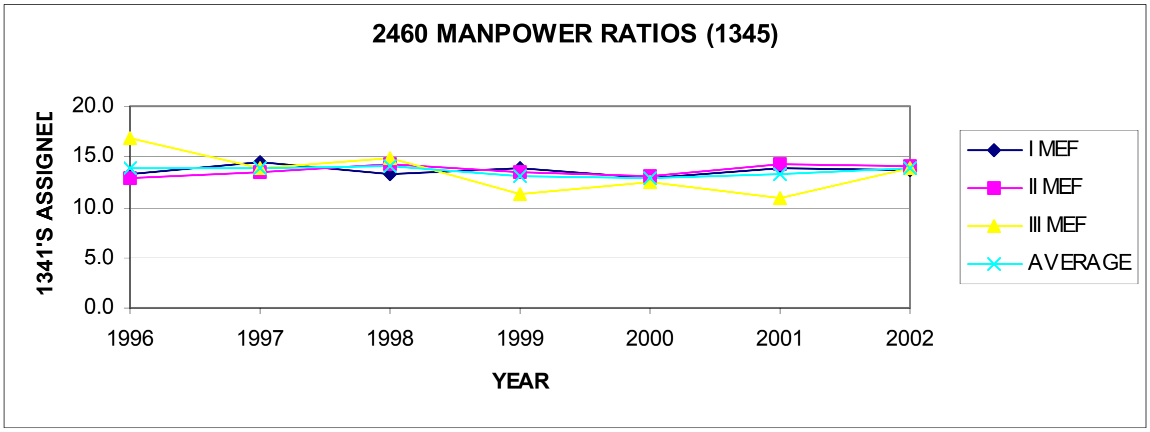

Figure 4-8: MC1150 Ratios

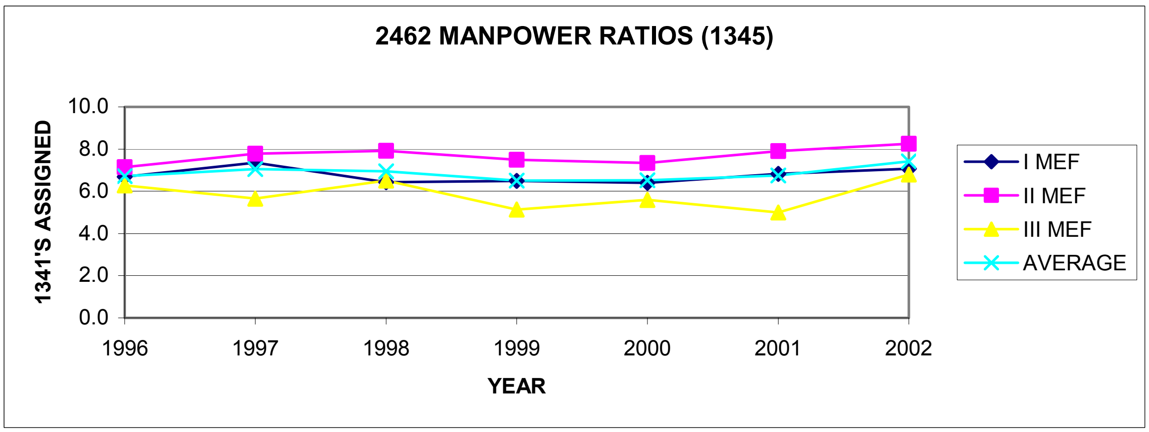

Figure 4-9: D7G Ratios

For the purposes of the model, it is assumed that there are sufficient maintenance technicians to accomplish required maintenance tasks. Furthermore, any manpower deficiencies that affect overall capacity are reflected within the model as decreases in operational readiness due to maintenance, as opposed to supply or transportation-caused non-availability.

To include the changes in manpower in the models, a normal distribution was used in the CELL: DEFINE ASSUMPTION box of Crystal Ball. For each MEF, the mean of the seven yearly operator-to-equipment ratios for each MEF and each BTAM were obtained, along with their standard deviations, using Excel.

Recommendation: The ratio of personnel to equipment is an extremely important metric needed to support a conclusion that there is in fact too much equipment being maintained by the Marines, at the expense of quality upkeep to maximize the life expectancy of the gear. While the graphs below don't conclusively show anything with respect to manpower trends, continued observance is warranted. Seven data points are not particularly useful in drawing conclusions in this case. It would be more useful and timely to obtain data directly from each MEF on a weekly basis, along with the readiness data. This would require only one more data field, specifically reporting the number of operators and technicians on at least a monthly basis.

5. Operators Assigned

The number of available operators is obtained by multiplying the operator-to-equipment ratio by the on-hand quantities of equipment. This quantity provides the baseline for modification by the next two factors to obtain the net number of operators available at any given time to operate a given item.

6. Manpower Utilization Factor

A factor that ranges between zero and one. This is a management factor that acknowledges the fact that even though operators may be assigned to a unit, not all of their time is available to operate construction equipment. Examples of non-value added time, at least as far as horizontal construction capacity is concerned, are administrative tasks, leave, physical readiness training, medical appointments, and many others. To truly determine the number of operators available, it is necessary to account for the periodic other tasks Marines must perform.

7. BTAM-Specific Operations Percentage

This factor also ranges between zero and one. In order to determine the number of operators available to operate a D7G, as opposed to a grader for example, it is necessary to know how operator man-hours are allocated among the many different construction equipment items they are trained to use. This factor is obtained by dividing the hours per period spent operating each specific BTAM by the number of hours during the same period that were available to operate equipment. The sum total of this factor for all BTAM's cannot exceed 1.0, or 100 percent.

Recommendation: Consider this example: Assume a 50-hour workweek, and that the manpower utilization factor is 0.5. This means that an operator is available to use construction equipment for 25 hours per week. The operator completes an operator log for the week that shows he logged the following hours:

BTAM	OPERATING TIME		BTAM OPERATING %
1082 Grader	5	Hrs	= 5/25 = .20
1922 Scraper	2	Hrs	= 2/25 = .08
2460 MC 1150	10	Hrs	= 10/25 = .40
2462 D7G Bulldozer	6	Hrs	= 6/25 = .24

This factor can and should be tracked at the unit level through the use of operator usage logs. A database system can be developed to track operator hours and the apportionment of their time among the various equipment items. If not feasible to maintain this data over the long-term, it is important to at least gather a ballpark estimate of this factor by tracking of a prototype unit for a pre-determined length of time.

8. Operators Available

The number of operators is computed for all models by multiplying the number of operators assigned by both the manpower utilization factor and the BTAM-specific operations percentage.

9. Usable Machines

The number of usable machines is the minimum of mission capable (non-deadlined assets) or number of operators available. This is simply because a MEF cannot run more machines than there are personnel to operate them. To evaluate surge capacity situations, the models provide forecasted results both with and without manpower constraints (e.g. if personnel were available to operate all machines).

D. BULLDOZER MODEL ELEMENTS, ASSUMPTIONS, AND RECOMMENDATIONS

Note: Values shown in the model illustrations below are for use only as examples, and don't reflect conclusive capacity findings. Their purpose is to show how the spreadsheets are constructed and how they are intended to work.

1. Governing Equation

Bulldozer production rates are computed by first determining a 'maximum uncorrected production", "based on numerous field studies made under varying job conditions"[39] from the Caterpillar Performance Handbook. Maximum rates depend on blade type, and the average dozing distance for a given task. Correction factors are then applied as detailed next, which transform the maximum production rate into a rate that corresponds to actual job conditions. The governing equation is:

Production (LCY/hr) = Maximum production * Correction factors

2. Operator Skill Level

This factor accounts for variations in operator experience and skill. Caterpillar uses 0.6 for poor, 0.75 for average, and 1.0 for excellent operators. For model purposes, a triangular distribution of .6 (minimum), .75 (most common), and 1.0 (highest), was incorporated. The actual distribution may be substantially different for the Marine Corps based on training, operator proficiency, and other factors. This factor is a multiple in the final rate equation.

3. Grade

Grade (in percent), with positive grades uphill, negative grades downhill. Enter as a whole number, not as a decimal. The initial assumption for the model is that grades for all jobs are normally distributed with a mean value of zero (level ground), and a standard deviation of 10 percent. Reality may be quite different.

Recommendation: Job history reports should be used as the basis for forming an accurate mathematical distribution of how grade varies in reality.

4. Soil Density

Maximum productivity values are based on soil density of 2300 lb/LCY. The Excel and Crystal Ball files provide soil density values for most common soil types, both in their loose and banked states. The weigh correction factor accounts for soil density in the final production computation.

[39] Caterpillar Inc. (2000), Caterpillar® Performance Handbook, Edition 31, Peoria, IL; Pg. 1-42.

Inputs	I MEF
Asset Management Factors	
Utilization (Hrs/Day)	3
Total D7G's On-hand	64
Usable Machines	53
Machine Factors	
Operational Availability	83%
D7G's Not In AWM/AWP/TRANS Status	53
Operator Factors	
Operator/Equipment Ratio	6.76
Operators Assigned	432
Operator Skill Level	0.85
Manpower Utilization Factor	0.5
D7G Operations Percentage	0.25
Operators Available	54
Task Factors	
Grade (Negative for Downhill/Positive for Uphill/Zero for Level Ground)	0
Soil Density (lb/LCY)	2650
Dozing Distance (Linear Feet)	50
Operator Job Efficiency (Minutes per Hour: Maximum of 50)	50
Load Factor	1
Correction Factors	
Maximum Production (LCY/Hr)	730
Weight Correction	0.8679
Cutting Difficulty (Loose=1.2; Cohesive, Frozen, or Sticky=0.8; Rock (Ripped or Blasted)=0.6	0.8
Grade Correction Factor	0.9857
Slot/Side by Side Correction	1.20
Job Efficiency Factor	0.83
Per-Machine Hourly Production (LCY/Hr)	**368.3**
Per-MEF Hourly Production With Manpower Constraint (LCY/Hr)	**19,564**
Per-MEF Hourly Production Without Manpower Constraint (LCY/Hr)	**19,564**
Daily MEF Capacity With Manpower Constraint	**58,692**
Daily MEF Capacity Without Manpower Constraint	**58,692**
Total Daily Capacity With Manpower Constraint	**132,457**
Total Daily Capacity Without Manpower Constraint	**142,014**
Total Daily Capacity With Manpower Constraint (Less IV MEF)	**116,176**
Total Daily Capacity Without Manpower Constraint (Less IV MEF)	**121,284**

Table 4-3: Bulldozer (D6/D7G) Model

5. Dozing Distance

The average distance material must be moved during dozing operations, in linear feet. Used to determine maximum possible production.

6. Operator Job Efficiency

The input for this cell is the number of minutes per hour a bulldozer is actually in motion on the jobsite. Caterpillar lists 40 and 50 minutes per hour as common values. As an initial input, this is assumed to be uniformly (equally) distributed between 40 and 50 minutes per hour.

Recommendation: Bulldozer operations should be sampled on a random basis, to identify reasonable nominal values for this variable.

7. Load Factor

Represents the ratio of loose material density, in Lb/Yd^3, to banked material density for a given material. These values are also listed in the included soil density chart. Production rates in LCY per hour can be converted into BCY/hr by the relationship:

$$\mathbf{BCY/hr = LCY/hr * Load\ factor}$$

8. Maximum Production

The Caterpillar handbook provides production rate charts as described earlier. The charts allow users to determine maximum production rates for a known bulldozer and blade type, for a given average dozing distance. However, these charts do not include the equations from which they were constructed. For purposes of building the model, we used manually chosen data points from the Caterpillar graphs, and used least squares regression in conjunction with Excel Solver to identify the coefficients "a" and "b" for an equation of the form[40]:

$$\mathbf{y = aX^b}$$

Where:

y = Computed maximum production rate

X = Average dozing distance

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40 Daniel, Cuthbert, Wood, Fred S., Gorman, John W.; Pg.21; *Fitting Equations to Data: Computer Analysis of Multifactor Data*. John Wiley & Sons, New York, 1980.

The resulting equations are as follows for the D6 and D7G. Figures 4-10 and 4-11 show against the plotted points actually read from the Caterpillar graphs to show the closeness of the fit.

D6 with straight blade: **Max Prod rate = 17108 * $X^{-.8909}$**
D7G with straight blade: **Max Prod rate = 13885 * $X^{-.7530}$**
D7G with universal blade: **Max Prod rate = 13350 * $X^{-.6823}$**

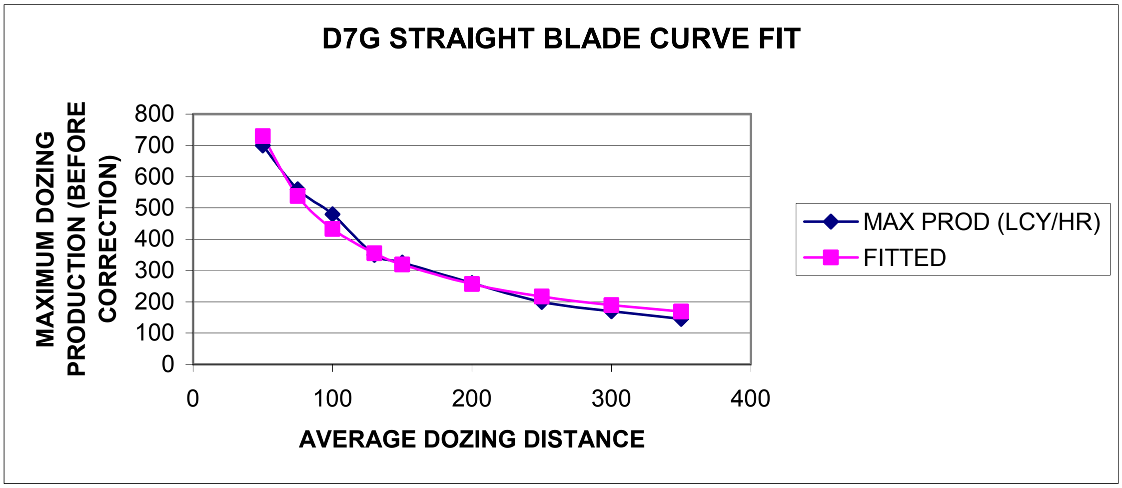

Figure 4-10: D7 Straight Blade Maximum Production (Fitted Vs. Graphical)

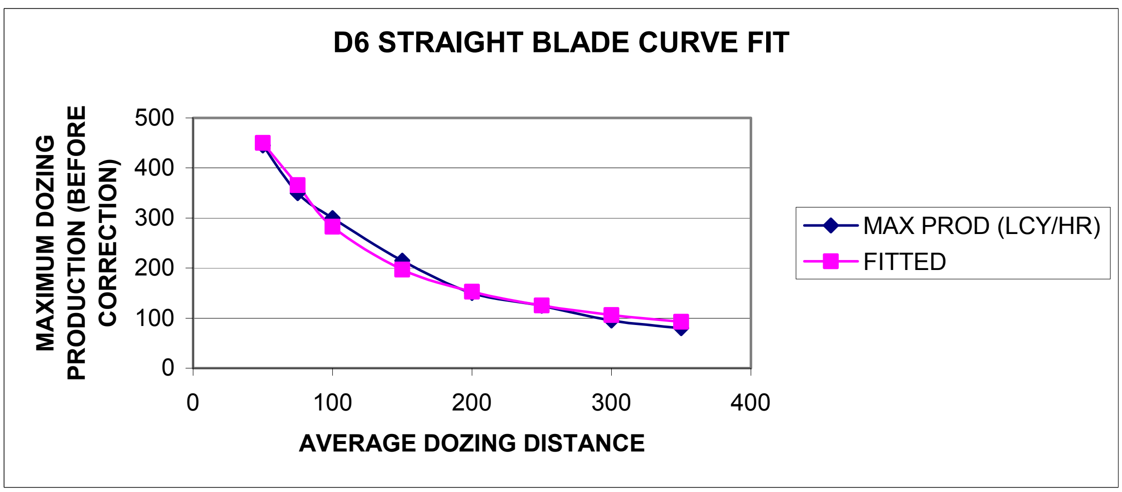

Figure 4-11: D6 Straight Blade Maximum Production (Fitted Vs. Graphical)

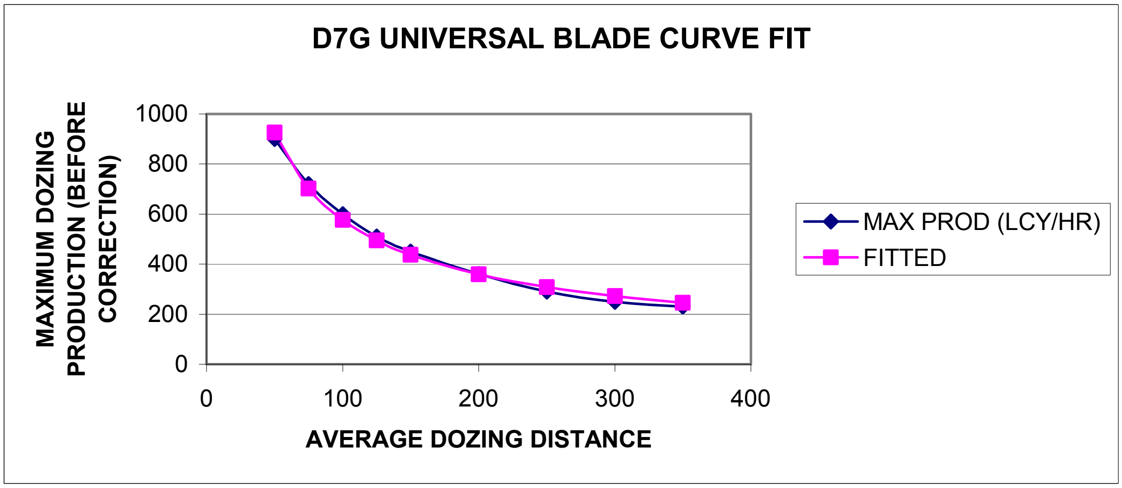

Figure 4-12: D7G Universal Blade Maximum Production (Fitted Vs. Graphical)

The fitted equations shown in bold are the ones incorporated in the spreadsheet models to determine maximum production rates. The input required to drive this computation is average dozing distance. As an initial input to the bulldozer models, a uniform distribution between 50 and 400 feet has been put into the models (d6 and D7G). This assigns an equal probability to all dozing distances between the two distance values. For purposes of machine capability comparison, figure 4-13 shows the comparison of the D6 and D7G, both with straight blades.

Recommendation: job logs should be maintained to determine the true variability in dozing distance lengths. For capacity determination, this information is well worth the minimal time it requires to document and report, because of the high dependence of production rates on this variable.

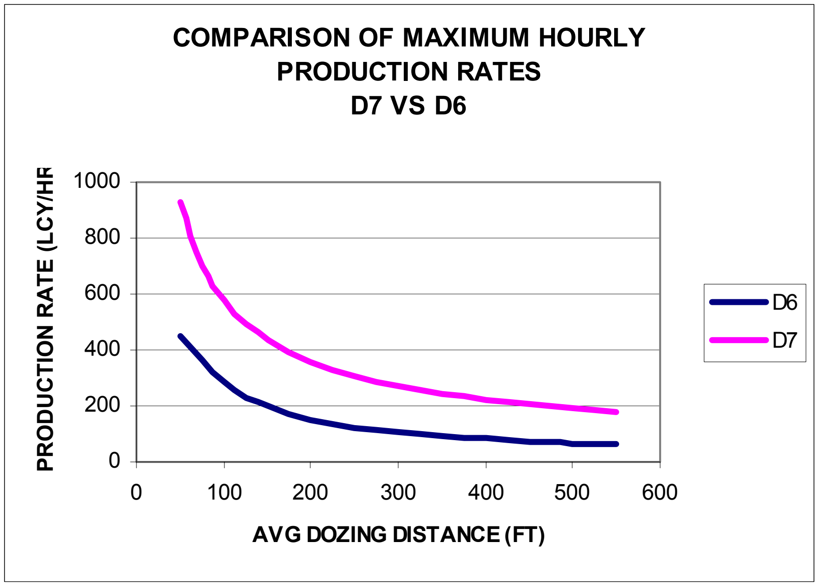

Figure 4-13: D6/D7G Maximum Production Rate Comparison

9. Weight Correction

Using 2300 lb/LCY as the baseline, this correction value is the ratio of the baseline density to the soil density for job-specific materials. For more dense materials, this value is less than 1.0, and for materials less dense than 2300 lb/LCY the factor is greater than 1.0.

Recommendation: As with dozing distance, a reasonable assumption, preferably based on actual job histories, should be made to simulate the typical array of materials handled in USMC applications.

10. Cutting Difficulty

The final rate equation must account for the type of material to be dozed in terms of how easily the blade can negotiate its forward progress through the material. Typical values are listed by Caterpillar as shown in Table 4-4.[41] The model as delivered again assumes a uniform distribution between 0.6 and 1.2.

[41] Caterpillar Inc. (2000), Caterpillar® Performance Handbook, Edition 31, Peoria, IL; Pg. 1-45.

Material	Cutting Difficulty Factor
Loose Stockpile	1.2
Hard to cut; Frozen; With tilt cylinder	0.8
Without tilt cylinder	0.7
Cable-controlled blade	0.6
Hard to drift; "dead" (dry, non-cohesive material), or very sticky material	0.8
Rock, ripped or blasted	0.6 – 0.8

Table 4-4: Cutting Difficulty Factors For Several Materials

Recommendation: A reasonable assumption, preferably based on actual job histories, should be made to simulate the typical array of materials handled in USMC applications.

11. Grade Correction Factor (GCF)

As expected, this factor enhances productivity for downhill grades and is greater than one, is equal to one for level ground, and less than one for uphill grade operations. This factor varies extremely close to linearly with grade, between ± 30 percent, according to the equation, derived using linear regression based on the graph provided by Caterpillar[42]:

GCF = (Grade * -0.021536) + 1

12. Slot/Side-by-Side Correction

This represents a bulldozing technique difference. For model purposes, it makes little difference, since the factor is 1.2 for slot dozing, and ranges between 1.15 and 1.25 for side-by-side dozing.

13. Job Efficiency Correction Factor

The number of minutes per hour of actual dozer usage was input previously in the model. This factor was found by linear regression to be equal to 0.0007143 + (0.0166429 * minutes/hour), for the range 0-60 minutes. The factor, as computed by this expression, is multiplied by the maximum production rate and the other correction factors to obtain the final production rate.

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[42] Ibid

14. Final Equation

The final equation for hourly production capacity is given by:

Hourly production = Maximum production * Operator Skill Level * Weight Correction Factor * Cutting Difficulty Factor * Grade Correction Factor * Slot/Side-by-Side Correction Factor * Job Efficiency Correction Factor

15. Results

The results of this model are given in terms of:

- Hourly production rates per machine
- Per-MEF hourly production rates
- Daily MEF capacities with and without manpower as a constraint
- Total daily capacity for MEF's I-IV
- Total daily capacity without including the Reserve (IV) MEF

E. GRADER MODEL ELEMENTS, ASSUMPTIONS, AND RECOMMENDATIONS

1. GOVERNING EQUATION

The production rate of graders depends upon three basic elements:

- Operating speed of the equipment (mph)
- Effective length of the blade
- Job efficiency

The general equation used to quantify production is given as:[43]

$$\mathbf{A = S \times (L_e - L_o) \times 5280}$$

A = Hourly operating area (ft^2/hr)
S = Operating speed (mph)
L_e = Effective blade length
L_o = Width of overlap (ft)
E = Job efficiency

[43] Ibid, Pg. 3-14

Inputs	I MEF
Asset Management Factors	
Utilization (Hrs/Day)	3
Total Graders On-hand	23
Usable Machines	19
Machine Factors	
Operational Availability	83%
Graders Not In AWM/AWP/TRANS Status	19
Operator Factors	
Operator/Equipment Ratio	19.07
Operators Assigned	439
Manpower Utilization Factor	0.5
Grader Operations Percentage	0.25
Operators Available	55
Task Factors	
Operator Job Efficiency (Typical Range .7-.85; Higher for Longer Passes)	0.75
Width of Blade Overlap (ft)	2
Moldboard Length (12 ft for 130G Model)	12
Blade Angle; Angle Between Blade and Direction of Grader Motion (Degrees; Often 30/45/60)	60
Effective Blade Length	10.39
Operating Speed (mph)	7
Width To Be Graded (ft)	22
Per-Machine Hourly Production (FT^2/Hr)	**232,635**
Per-Machine Hourly Production (Miles Graded Per Hour)	**2.00**
Per-MEF Hourly Production With Manpower Constraint (FT2/Hr)	**4,440,996**
Per-MEF Hourly Production Without Manpower Constraint (FT2/Hr)	**4,440,996**
Per-MEF Hourly Production (Miles Graded Per Hour)	
Daily MEF Capacity With Manpower Constraint	**13,322,989**
Daily MEF Capacity Without Manpower Constraint	**13,322,989**
Daily MEF Capacity (Miles Graded Per Day)	**114.70**
Total Daily Capacity With Manpower Constraint	**35,991,607**
Total Daily Capacity Without Manpower Constraint	**35,991,607**
Total Daily Capacity (Miles Graded Per Day)	**309.85**
Total Daily Capacity With Manpower Constraint (Less IV MEF)	**28,257,727**
Total Daily Capacity Without Manpower Constraint (Less IV MEF)	**28,257,727**
Total Daily Capacity (Less IV MEF); (Miles Graded Per Day)	**243.27**

Table 4-5: Grader Model

2. Job Efficiency

"Job efficiencies vary based on job conditions, operator skill, etc. A good estimation for job efficiency is approximately 0.70 to 0.85, but actual operating conditions should be used to determine the best value."[44] For the grader model, a

44 Ibid, Pg. 3-15

triangular distribution was assumed, with 0.70 as the minimum, 0.75 as the most likely, and 0.9 as the maximum, to account for highly skilled operators working in the most favorable conditions possible.

Recommendation: This factor can either be adjusted as users gain more confidence in the capacity forecasting model, or can be estimated for USMC operators in an experimental scenario, using operators with known differences in skill level to verify the efficiency factor range.

3. Width of Blade Overlap

Blade overlap must be subtracted from the effective blade length so that only the "new" ground that is covered is included in the productivity equation. Caterpillar cites two feet as a general standard, but this may vary depending on training and actual practice. A set value of two feet is used initially for the model.

4. Moldboard Length

The Caterpillar 130 G model referenced in the ROC document[45] is equipped with a 12-foot moldboard.[46]

5. Blade Angle

Blade angle is defined as the angle between the plane perpendicular to the grader's direction of travel and the moldboard. At zero degrees, the effective blade length equals the actual blade length, and at 90 degrees the effective blade length is zero. The ROC requires a minimum of six pitch positions for USMC graders.[47]

Recommendation: The Crystal Ball Grader Model assumption is that in practical use, blade angles vary according to a triangular distribution, with 30, 45, and 60 degrees as the lowest, most common, and highest possible values respectively. Actual usage data, or a more educated estimate of this distribution will make the forecasted productivity more accurate.

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[45] Heavy Motorized Road Grader Required Operational Capability Document, Marine Corps Systems Command, Updated 6 July 1999.

[46] Caterpillar Inc. (2000), Caterpillar® Performance Handbook, Edition 31, Peoria, IL; Pg. 21-22.

[47] Heavy Motorized Road Grader Required Operational Capability Document, Marine Corps Systems Command, Updated 6 July 1999.

6. Effective Blade Length

Effective blade length is computed automatically in the model by multiplying the 12-foot moldboard length by the sine of the blade angle.

7. Operating Speed

Operating speed is a critical element in capacity estimation for the grader. Typical speeds[48] for various types of grader operations are given in Table 4-6.

Application	Operating Speed (mph)
Finish Grading	0 - 2.5
Heavy Blading	0 - 6
Ditch Repair	0 - 3
Ripping	0 - 3
Road Maintenance	3 - 9.5
Haul Road Maintenance	3 - 9.5
Snow Plowing	4 - 13
Snow Winging	9 - 17

Table 4-6: Typical Equipment Speeds For Grader Operations

Recommendation: Experienced operators should be consulted to develop a distribution that accurately reflects the realistic pattern of speeds for grader operations. To begin the analysis, a triangular distribution (0, 7, 10) distribution has been incorporated into the model.

8. Width to Be Graded

In feet, this should normally be the width of a standard road, runway, or haul road. By specifying this parameter, the production rate computed in units of square feet per hour is converted into the more readily useful units of miles graded per hour.

9. Results

The final equation for hourly production capacity is given by:

$$\text{Production Rate (Graded mph)} = \frac{(\text{S } x \text{ } (\text{L}_e - \text{L}_O) \text{ } x \text{ Efficiency}}{\text{Width of Road Graded}}$$

[48] Caterpillar Inc. (2000), Caterpillar® Performance Handbook, Edition 31, Peoria, IL; Pg. 3-14.

As with the bulldozer models, the results of this model are given in terms of:

- Hourly production rates per machine
- Per-MEF hourly production rates
- Daily MEF capacities with and without manpower as a constraint
- Total daily capacity for MEF's I-IV
- Total daily capacity without including the Reserve (IV) MEF.

F. SCRAPER MODEL ELEMENTS, ASSUMPTIONS, AND RECOMMENDATIONS

Inputs	I MEF
Asset Management Factors	
Utilization (Hrs/Day)	3
Total Scrapers On-hand	10.6
Usable Machines	8
Machine Factors	
Beta Distribution Computation For Operational Availability	73%
Operational Availability	73%
Scrapers Not In AWM/AWP/TRANS Status (Mission Capable Assets)	8
Cost per Operating Hour	
Operator Factors	
Operator/Equipment Ratio	40.70
Operators Assigned	431
Manpower Utilization Factor	0.5
Scraper Operations Percentage	0.25
Operators Available	54
Empty Scraper	
Tractor Weight (Empty) (LBS)	71,090
Load Weight (LBS)	-
Total Weight (LBS)	**71,090**
Empty Haul Distance (Miles)	1
Empty Haul Rolling Resistance Factor (LBS/Ton) (Hard Smooth Roadway =40; Gravel Road = 65; Hard Clay = 100; Soft Clay = 150; Muddy, Rutted, or In Sand = 400)	100
Empty Haul Grade (%; Positive=Uphill; Negative=Downhill)	10%
Empty Rolling Resistance (%)	5.0%

Inputs	I MEF
Empty Effective Grade (%; Positive=Adverse Grade; Negative=Favorable Grade)	**15.0%**
Maximum Attainable Empty Speed (Adverse Effective Grade)	9.13
Maximum Attainable Empty Speed (Favorable Effective Grade)	-
Level (0%) Effective Grade Empty Speed	-
Maximum Attainable Speed (mph)	9.13
Empty Scraper Travel Time (Minutes)	**6.57**
Loaded Scraper	
Tractor Weight (Empty) (LBS)	71,090
Load Weight (LBS)	48,000
Total Weight (LBS)	**119,090**
Full Haul Distance (Miles)	1
Full Haul Rolling Resistance Factor (LBS/Ton) (Hard Smooth Roadway =40; Gravel Road = 65; Hard Clay = 100; Soft Clay = 150; Muddy, Rutted, or In Sand = 400)	100
Full Haul Grade (%; Positive=Uphill; Negative=Downhill)	0%
Full Rolling Resistance (%)	5.0%
Full Effective Grade (%; Positive=Adverse Grade; Negative=Favorable Grade)	**5.0%**
Maximum Attainable Haul Speed (Adverse Effective Grade)	15.22
Maximum Attainable Haul Speed (Favorable Effective Grade)	-
Inputs	**I MEF**
Level (0%) Effective Grade Haul Speed	-
Maximum Attainable Haul Speed (mph)	15.22
Full Scraper Travel Time (Minutes)	**3.94**
Total Travel Time (Minutes)	**10.51**
Load Time (Minutes; Caterpillar Typical = 0.4)	**0.40**
Manuever & Spread, or Maneuver & Dump (Minutes; Caterpillar Typical = 0.7)	**0.70**
Total Cycle Time (Minutes)	**11.61**
Cycles Per Hour	**5.17**
Soil Density (LB/Yd3) (Loose/Bank: Clay=2800/3500 Wet, 2500/3100 Dry; Earth=2550/3200 Dry Packed, 2700/3400 Wet Excavated, 2100/2600 Loam; See attached table for other materials)	2,550
Yd^3 Per Cycle	**18.82**
Per-Machine Hourly Production (LCY/Hr)	**97.3**
Per-MEF Hourly Production With Manpower Constraint (LCY/Hr)	**753**
Per-MEF Hourly Production Without Manpower Constraint (LCY/Hr)	**753**
Daily MEF Capacity With Manpower Constraint	**2,258**
Daily MEF Capacity Without Manpower Constraint	**2,258**
Total Daily Capacity With Manpower Constraint	**6,046**
Total Daily Capacity Without Manpower Constraint	**6,046**
Total Daily Capacity With Manpower Constraint (Less IV MEF)	**4,464**
Total Daily Capacity Without Manpower Constraint (Less IV MEF)	**4,464**

Table 4-7: Scraper Model

1. Governing Equation

Scraper production is ultimately a function of the speed with which the equipment can complete a cycle comprised of four functions:

- Loading the scraper
- Hauling the load to the emptying point
- Maneuvering and spreading the loaded material
- Returning the empty scraper to the site to repeat the cycle

Determining the time required for completion of the four processes, then taking their sum yields the total cycle time for one evolution. Production capacity estimation begins with knowing how many cycles per hour/day can be completed based upon task-specific factors such as material being scraped, haul and return road lengths, grades and conditions, and the fixed times required for loading and spreading of material.

Cycle Time **= Load Time + Haul Time + Maneuver & Spread Time + Return Time**

For example, if:	Load time	=	2 minutes
	Haul time	=	6 minutes
	Maneuver & spread time	=	3 minutes
	Return time	=	4 minutes
	Cycle time	=	15 minutes

In this example, the scraper can complete 4 cycles per hour, and its production rate is equal to four times the capacity of the scraper, in LCY or pounds per hour.

The model inputs required for determining overall production capacity for scrapers are listed and described below. First, it is necessary to point out that scraper traveling speeds and road lengths are the most important variables to the model, since these variables directly determine two of the four cycle time functions. Operating speeds depend on the weight of the scraper, the surface the scraper is being operated on, and the grade of the haul and return roads.

2. Tractor Weight

This is the empty weight of the scraper. For the Caterpillar 621G, empty weight is given as 71,090 lb.[49]

[49] Caterpillar Inc. (2000), Caterpillar® Performance Handbook, Edition 31, Peoria, IL; Pg. 9-2.

3. Load Weight

The capacity of the 621G Scraper is given as 48,000 lbs or 20 LCY.[50] For model purposes, the scraper is assumed to be filled to capacity when loaded. "If you aren't leaving the cut at 100% capacity, I would be FIRING my cut Boss. 100% full."[51]

4. Haul Distance (Empty and Full)

The model uses the length of the road traveled by the scraper when empty and loaded, in miles. For the model's initial assumption in Crystal Ball, a TRIA (0.5, 2, 5) distribution is used.

Recommendation: Experienced operators should be able to more accurately describe the real-world distribution of haul road distances. As recommended for other parameters, job logs kept that reflect actual site conditions will give a more accurate input for this assumption as well.

5. Road Grade (Empty and Haul)

Grade (in percent) of the road the scraper travels when empty. Like the bulldozer models, positive grades are uphill, negative grades downhill. Enter as a whole number, not as a decimal. The initial assumptions for the model are TRIA (-30, 0, 20), for both empty and loaded scrapers.

Recommendation: Job history reports should be used as the basis for forming an accurate mathematical distribution of how grade varies in reality.

6. Rolling Resistance Factor and Rolling Resistance

Rolling resistance is a measure of the resistance to motion caused by the surface on which the scraper is being operated. The rolling resistance factor is low for harder and smoother surfaces, such as paved roadways, and highest for muddy, rutted, or sandy surfaces. To obtain rolling resistance (measured in percent), the rolling resistance factor (given in lbs/ton) is divided by 20 lb/ton **(1% adverse grade = 20 lb/ton)**, and then

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50 Ibid

51 E-mail dated 25 Apr 2003 from Master Chief Equipmentman (SCW) Ronald W. Komoroski, Senior Enlisted Advisor, Navy Detachment, Fort Leonard Wood, MO

divided by 100 to yield the total rolling resistance in percent. Examples for various surfaces are given in Table 4-8.

	Hard, Smooth Roadway	**Gravel Road**	**Hard Clay**	**Soft Clay**	**Muddy Roadway**
Rolling Resistance Factor	40 lbs/ton	65 lbs/ton	100 lbs/ton	150 lbs/ton	400 lbs/ton
Conversion Factor	20 lbs/ton	20 lbs/ton	20 lbs/ton	20 lbs/ton	20 lbs/ton
Rolling Resistance	**2 %**	**3.25 %**	**5 %**	**7.5 %**	**20 %**

Table 4-8: Typical Rolling Resistance Factors

7. Total Resistance/Effective Grade

Total resistance and effective grade are synonymous. Effective grade is the sum of road grade and rolling resistance. If the sum is positive, the effective grade is ***adverse***, and ***favorable*** if the effective grade is negative. Again, all uphill grades are positive, and downhill grades are negative. All rolling resistance values are positive.

Total Resistance/Effective Grade = -10% grade + 2% rolling = **-8% (Favorable)**

8. Maximum Attainable Speed (Adverse Grade)

The top speed achievable by the 621G Scraper is 33.5 mph.[52] Operating speeds are dependent upon the gross weight of the scraper and total resistance. The Caterpillar Performance Handbook uses a series of charts that require a three-step process to determine the operating speed for a known situation. This is impractical for a simulation model that seeks to dynamically analyze scraper production. Our solution was to plot operating speed values for effective grades ranging from two to thirty percent, then use least-squares regression to determine an equation with only one independent variable.

[52] Caterpillar Inc. (2000), Caterpillar® Performance Handbook, Edition 31, Peoria, IL; Pgs. 9-22/23, Rimpull-Speed-Gradeability and Retarding Charts.

This process was completed for both empty and loaded machines. The resulting equations are:

Empty: **Operating Speed = 111.528 * Total Resistance$^{-.9242}$**

Full: **Operating Speed = 60.73 * Total Resistance$^{-.8598}$**

Figures 4-14 (Empty) and 4-15 (Loaded) show the plots of manually plotted operating speeds versus those predicted by the derived equations. The technique for curve fitting was identical to that used for determining maximum bulldozer production equations for a function of the form; $\mathbf{y = aX^b}$.

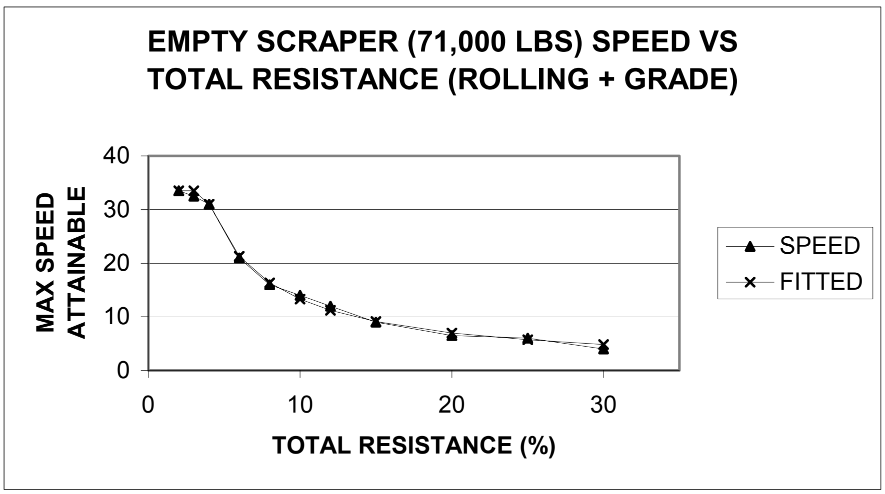

Figure 4-14: Empty Scraper Speed On Adverse Grades

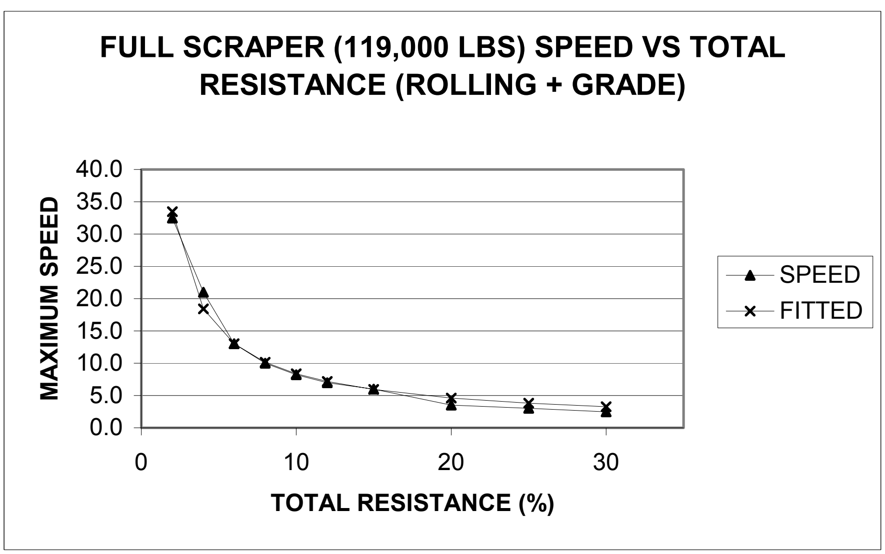

Figure 4-15: Full Scraper Speed On Adverse Grades

9. Maximum Attainable Speed (Favorable Grade)

In the case of favorable total resistance in a downhill situation, scraper speed must be controlled using a "retarder". The Caterpillar Performance Handbook uses Retarding Curves (also a three-step process) to determine operating speed. In the same manner as before, for adverse grades, favorable operating speed equations were determined to be:

Empty: **Operating Speed = 55.98 * -(Total Resistance)$^{-.50}$**

Full: **Operating Speed = 33.88 * -(Total Resistance)$^{-.465}$**

Figures 4-16 and 4-17 show the graphs of manually plotted operating speeds versus those predicted by the derived equations.

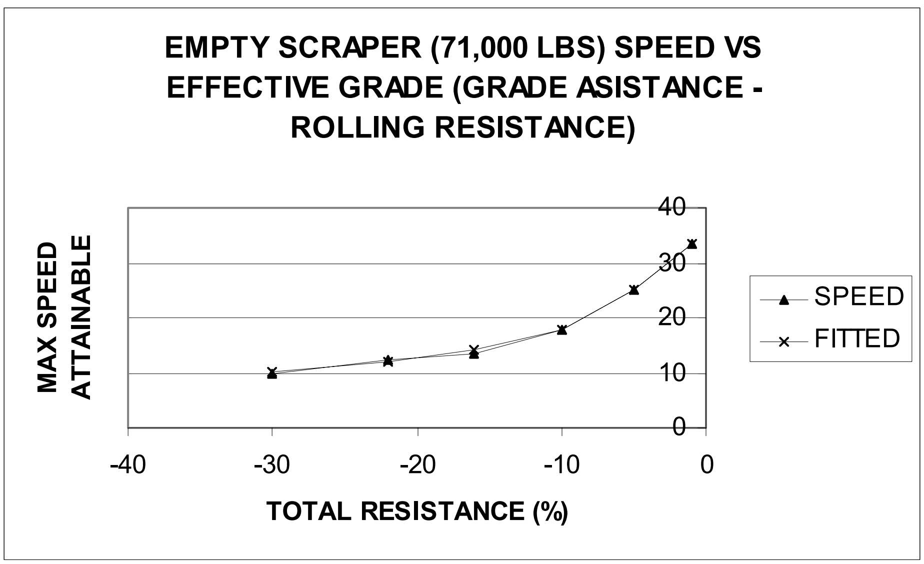

Figure 4-16: Empty Scraper On Favorable Grades

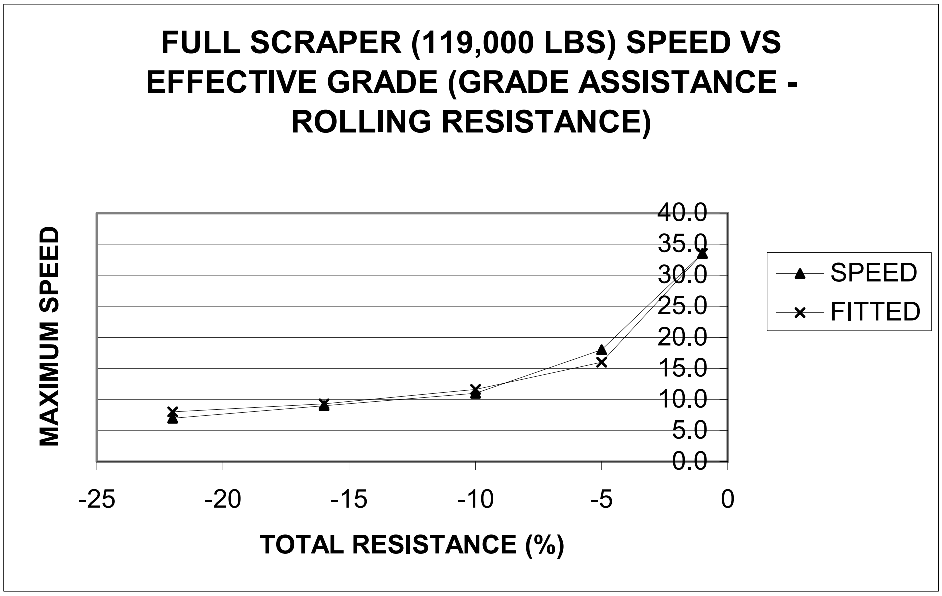

Figure 4-17: Full Scraper On Favorable Grades

10. Scraper Travel Time (Empty and Loaded)

With operating speeds now known, the empty and full travel times (in minutes) are computed by solving:

$$\text{Time} = \frac{\text{Distance (miles)}}{\text{Operating Speed (mph)}} * 60(\text{min}/\text{hr})$$

11. Total Travel Time

The sum of the empty and loaded travel times.

12. Load Time

Caterpillar gives representative values for the time needed to load the empty scraper to capacity. This time is dependent on the method of loading (self, dozer, auger, etc.). The time given for a 621G Scraper loaded by a D9R bulldozer is 0.4 minutes.[53] Absent any justification to make a different assumption, this value is the one initially used by the scraper production model.

53 Caterpillar Inc. (2000), Caterpillar® Performance Handbook, Edition 31, Peoria, IL; Pg. 9-11.

Recommendation: Actual loading times should be observed for a representative period of time to more accurately represent USMC operations.

13. Maneuver & Spread/Maneuver & Dump

The time elapsed while the scraper is positioned to offload is accounted for with this time. Similar to load time, Caterpillar lists 0.7 minutes as the nominal time required for the 621G.[54]

Recommendation: Actual loading times should be observed for a representative period of time to approximate USMC operations.

14. Cycles per Hour

After adding travel times to loading and unloading times to determine cycle time, determine the number of cycles per hour by dividing 60 minutes by the cycle time.

Recommendation: Though not currently factored into the model, it may be useful to incorporate a job efficiency factor to account for the likelihood that the scraper will be idle for short intervals during any given operating period.

15. Soil Density

All speed calculations to this point in the scraper model have been based on the weight of the scraper, meaning that the load has been described in terms of its weight. For consistency between this model and the bulldozer models, soil density is used to convert the load of a full scraper (48,000 lbs) to its equivalent volume. To account for the many materials handled in actual practice, a TRIA (1,000, 3,140, 5,500) is used for soils density within the Crystal Ball model. Soil densities for many common materials are given in a worksheet attached to the model.

16. Cubic Yards per Cycle

The full load capacity of 48,000 lbs is divided by the soil density, which yields the number of cubic yards (LCY) per cycle that are moved by the scraper.

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[54] Ibid

17. Results

To complete the model, the number of cycles per hour is multiplied by the number of cubic yards per cycle. The results of this model are given in terms of:

- Per Machine hourly capacity
- Per-MEF hourly production rates
- Daily MEF capacities with and without manpower as a constraint
- Total daily capacity for MEF's I-IV
- Total daily capacity without including the Reserve (IV) MEF.

18. Sample Model Results

Figures 4-18 through 4-33 provide sample results for the D7, MC1150/D6, Grader, and Scraper. This section is intended to show one method for interpreting the results. These models were run using the assumptions detailed in each model's respective description. For utilization, each model assumes a TRIA (0, 1.5, 12) (hours per day) distribution. The mean production capacity for each BTAM is shown by the dashed vertical line.

Results are given for MEF's I through IV, and also for I MEF alone so that there differences can be contrasted. For the "peacetime" simulation, the theoretical production level the MEF(s) should be able to attain nearly 75 percent of the time is indicated. For example, the D7 Peacetime frequency chart (Figure 4- 18) reveals that MEF's I-IV should be able to meet a capacity requirement of 67,833 LCY/Day approximately 74.8 percent of the time. A "surge" of 50 percent more than the 75 percent peacetime level was assumed for the surge case. (67,8336 * 1.5 = 101,750) Using Crystal Ball, it is very easy to determine that the new surge capacity level of 101,750 LCY/Day can be met only 45.8 percent of the time, given the model's assumptions and current equipment quantities. This procedure was repeated for each BTAM to show the dynamic of degraded ability to meet mission requirements as demand increases.

The benefit of these models is that they will permit decision makers to assess the level of risk that accompanies managerial decisions with respect to AAO levels. The key to making these models useful is to narrow the assumptions as much as possible through data collection during actual operations, then making reasonable judgments about anticipated requirements. It is left to I&L and the USMC equipment users to determine the proper balance between on-hand capacity, the magnitude of equipment quantity reductions, and an acceptable level of risk (as defined by the potential inability to satisfy operational requirements in a timely manner due to lack of equipment).

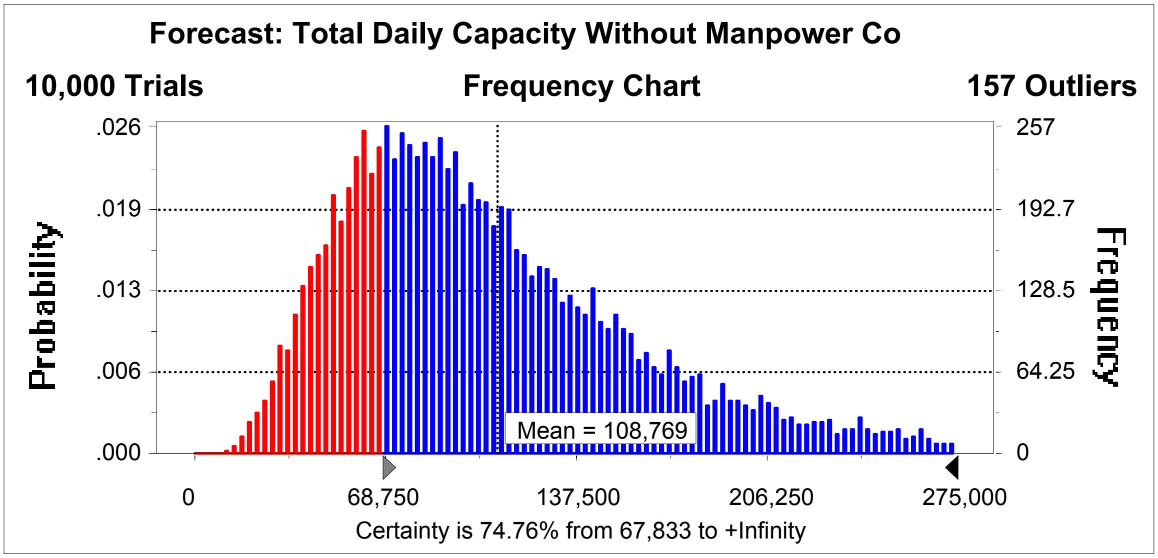

Figure 4-18: D7 Total Capacity (Peacetime)

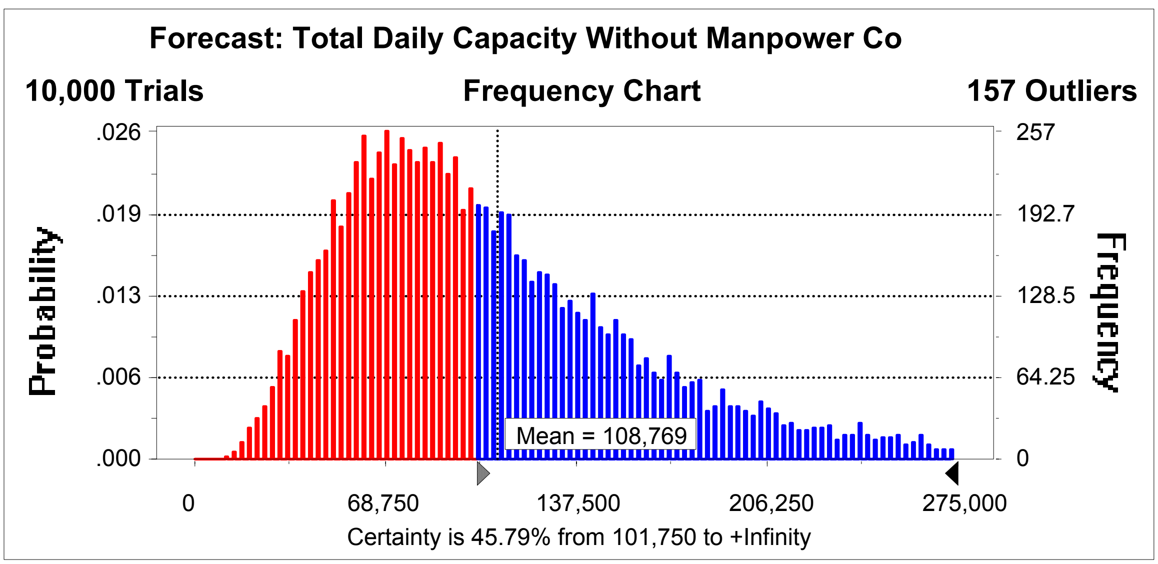

Figure 4-19: D7 Total Capacity (Surge)

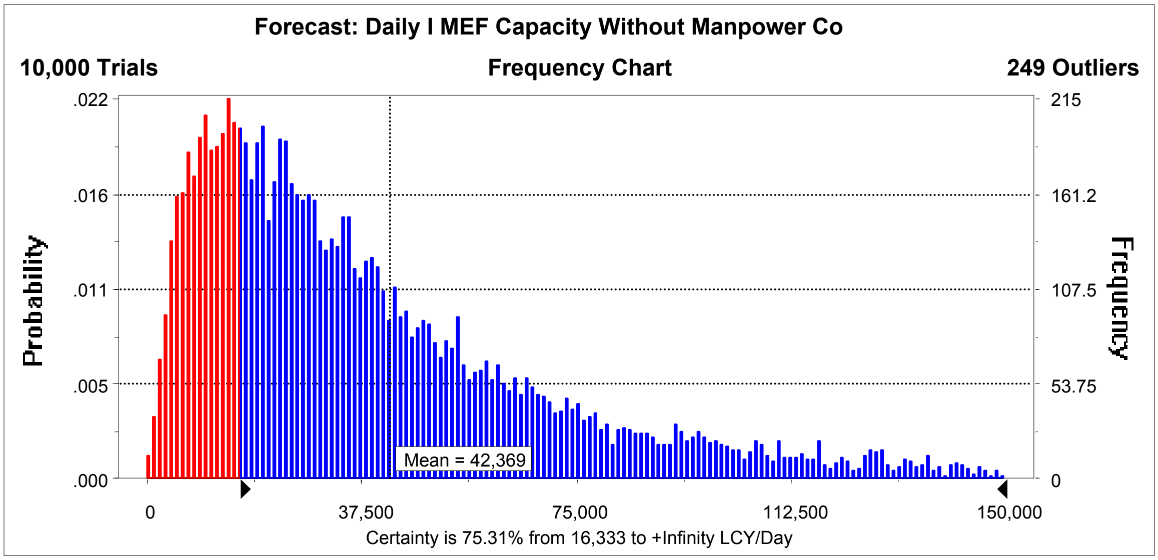

Figure 4-20: D7 I MEF Capacity (Peacetime)

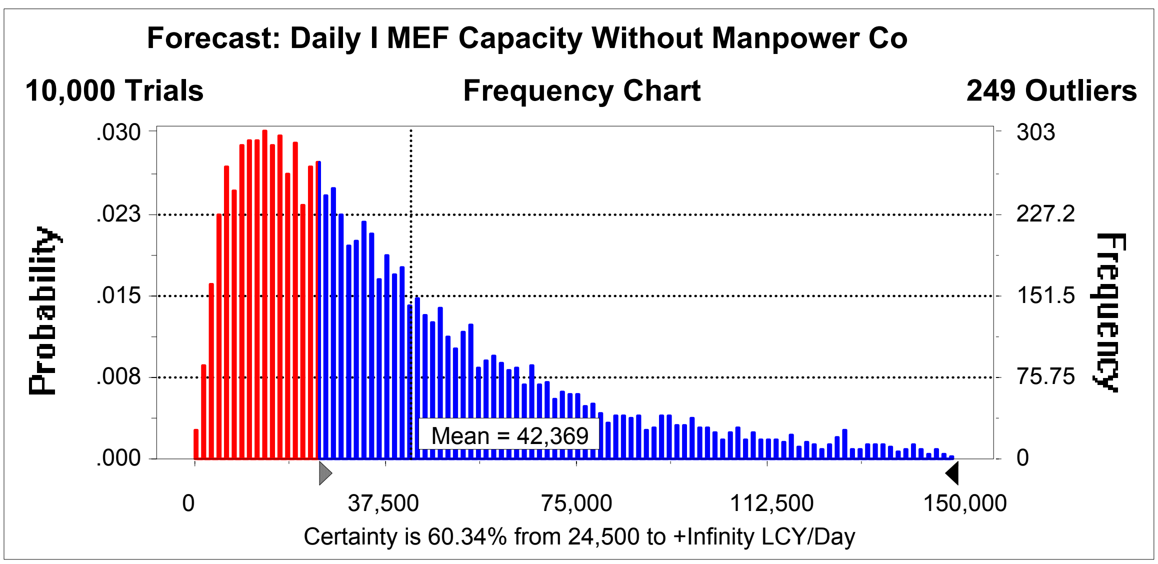

Figure 4-21: D7 I MEF Capacity (Surge)

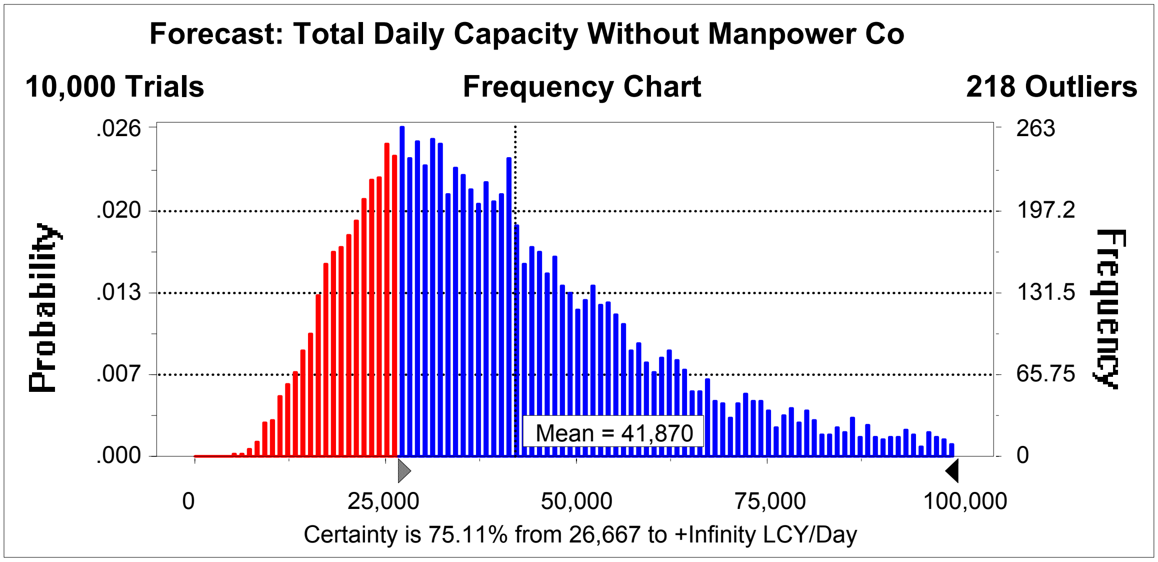

Figure 4-22: 1150 Total Capacity (Peacetime)

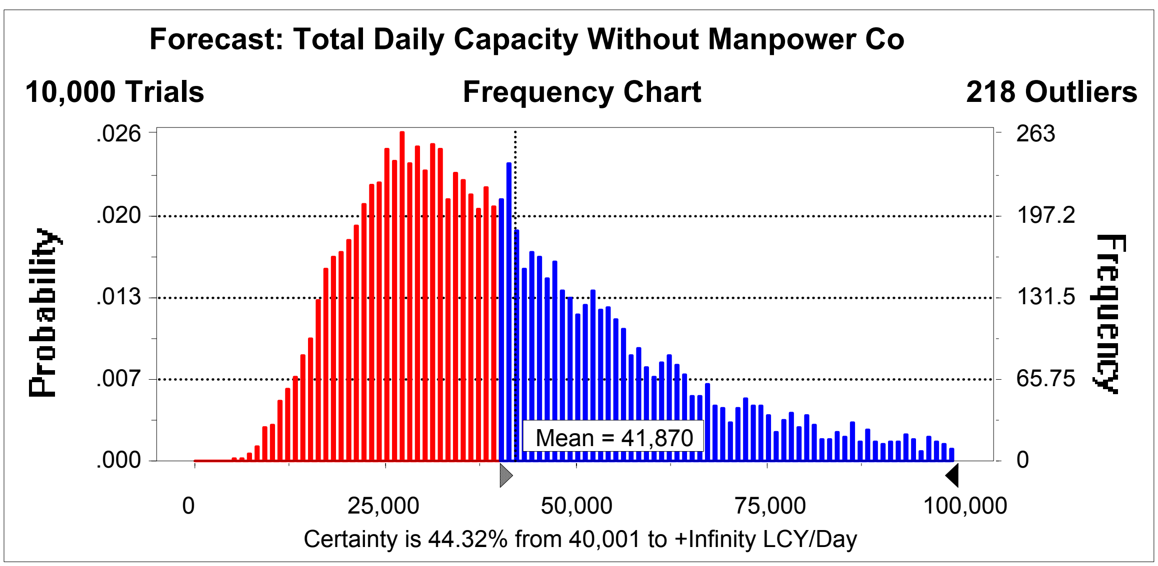

Figure 4-23: 1150 Total Capacity (Surge)

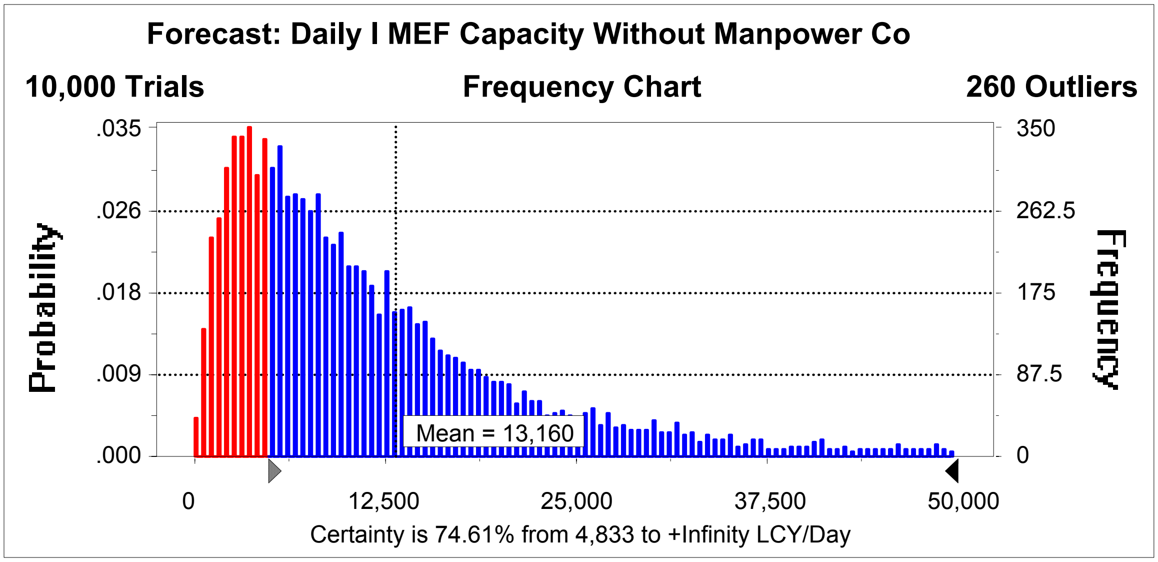

Figure 4-24: 1150 I MEF Capacity (Peacetime)

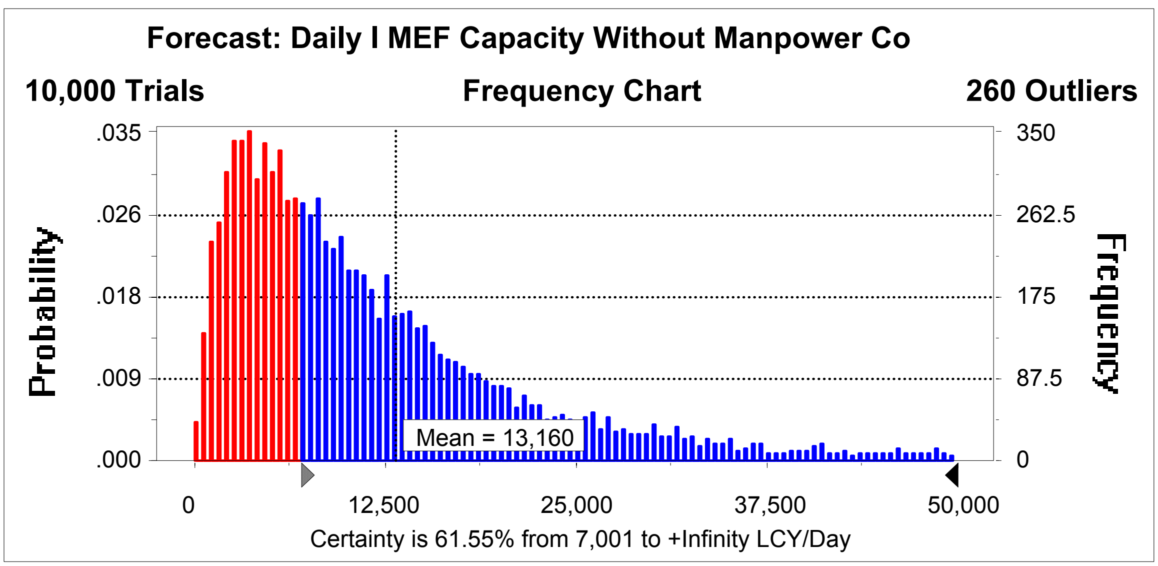

Figure 4-25: 1150 I MEF Capacity (Surge)

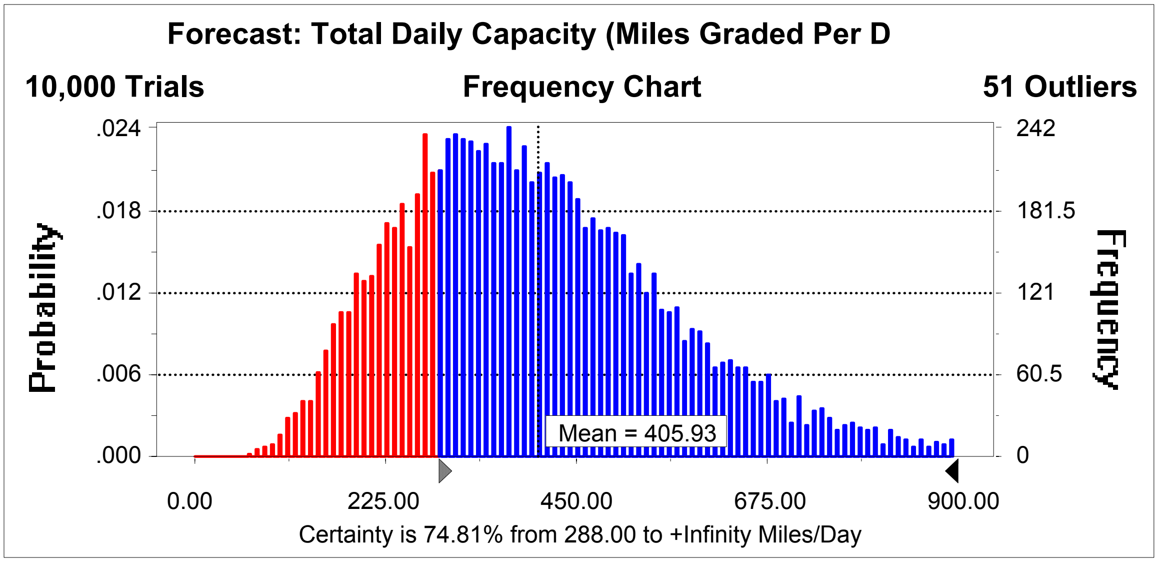

Figure 4-26: Grader Total Capacity (Peacetime)

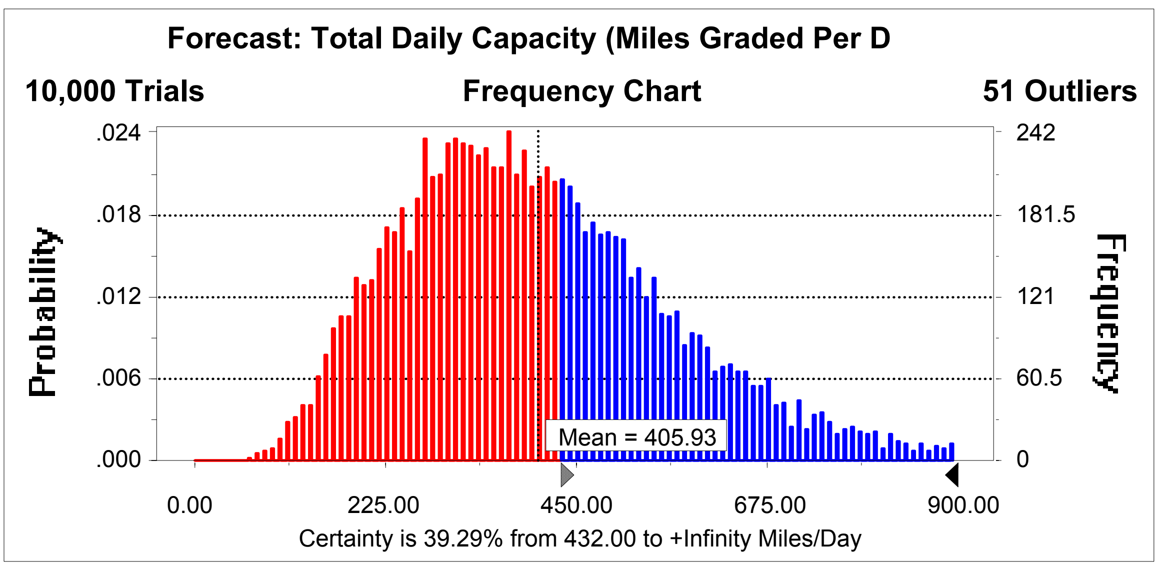

Figure 4-27: Grader Total Capacity (Surge)

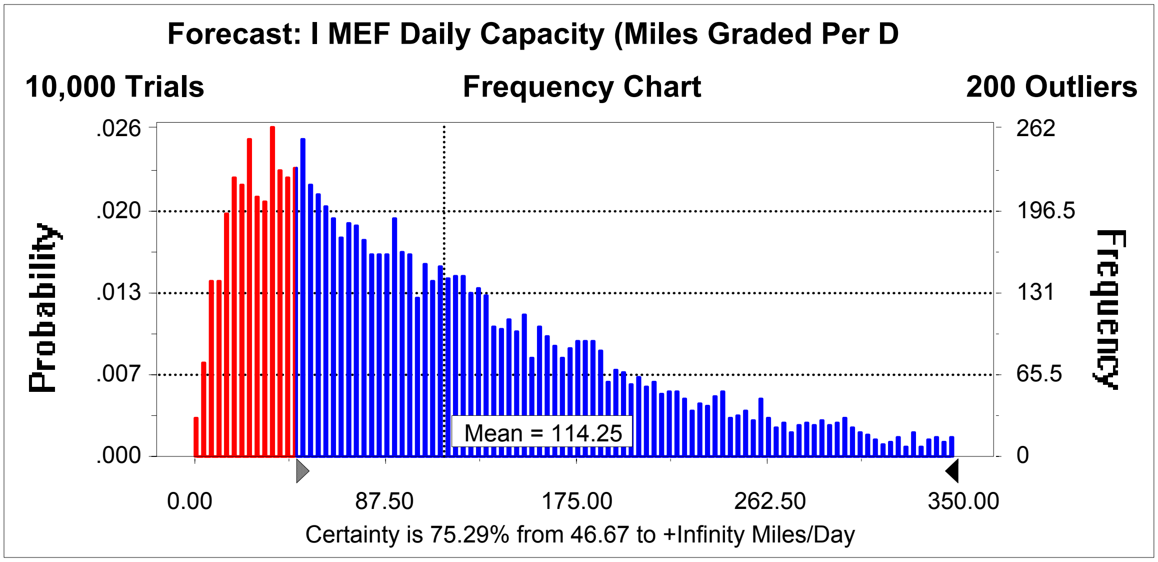

Figure 4-28: Grader I MEF Capacity (Peacetime)

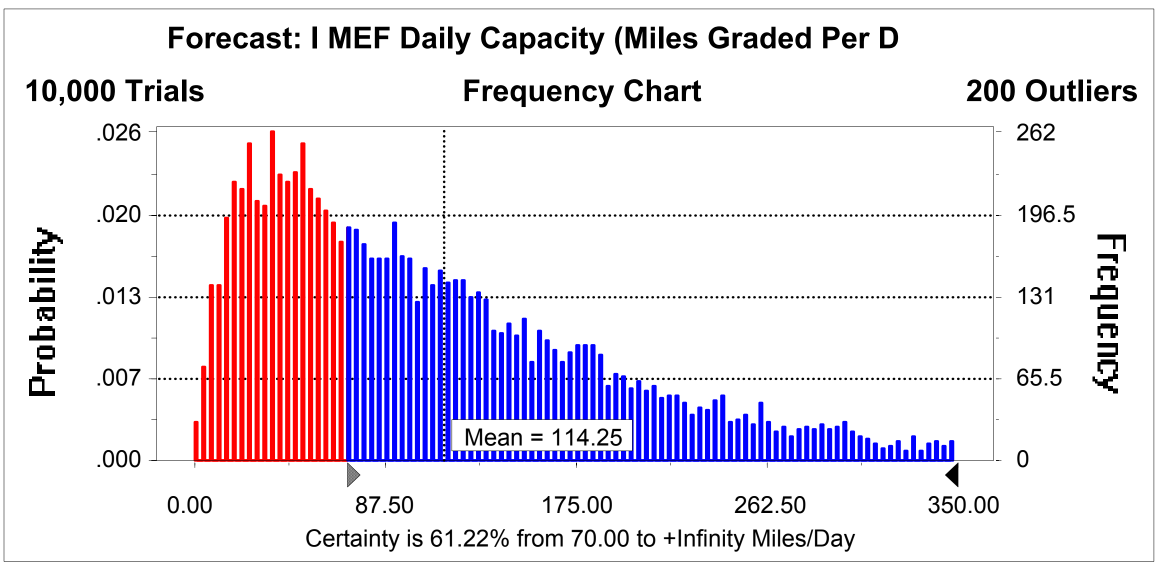

Figure 4-29: Grader I MEF Capacity (Surge)

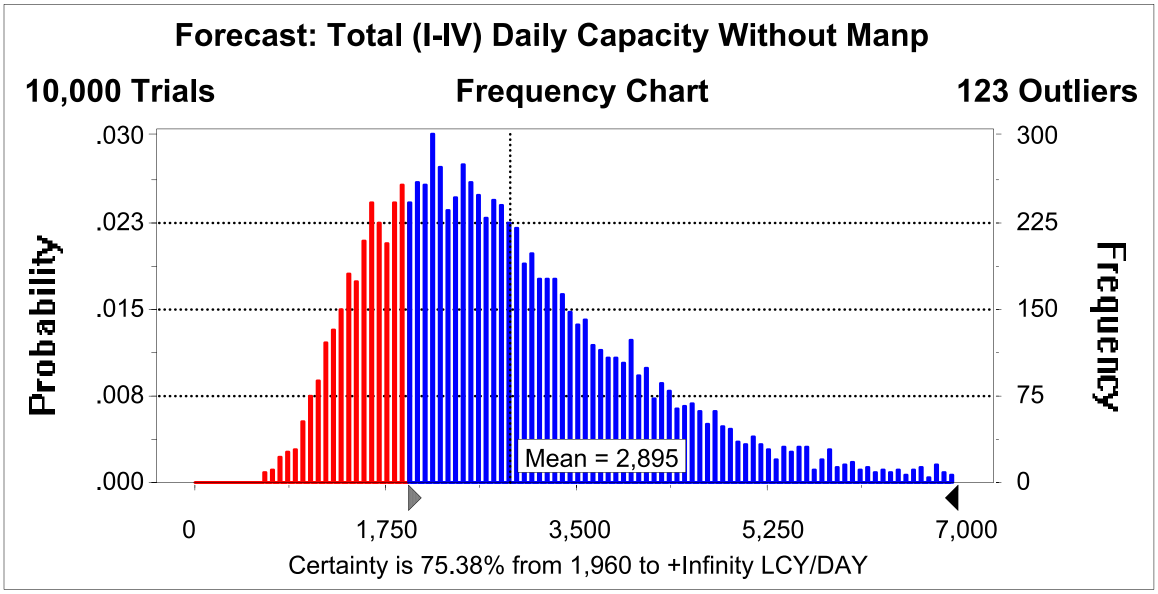

Figure 4-30: Scraper Total Capacity (Peacetime)

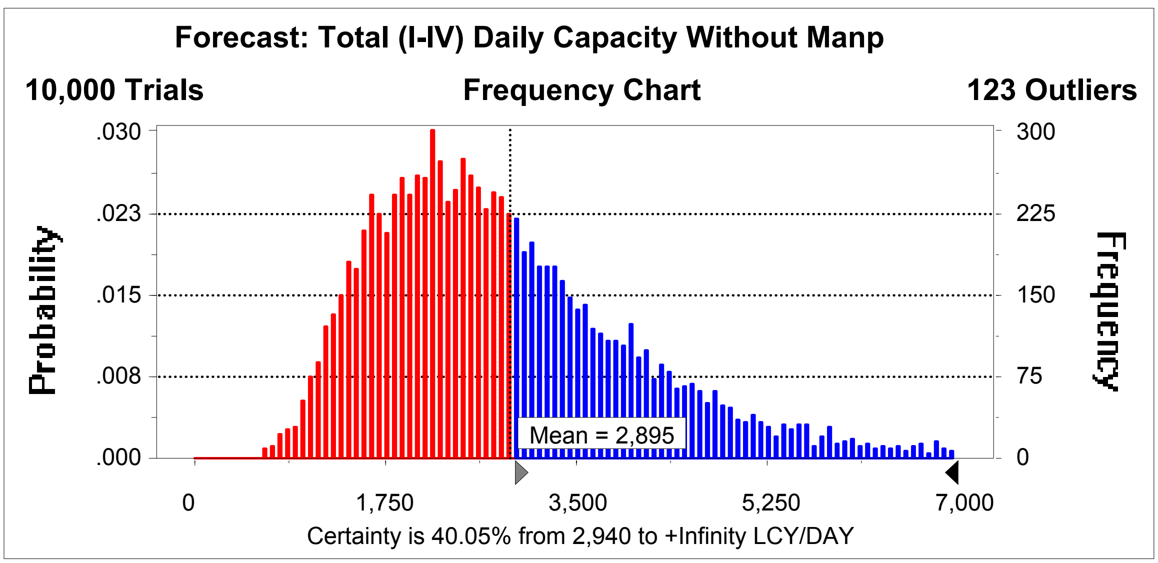

Figure 4-31: Scraper Total Capacity (Surge)

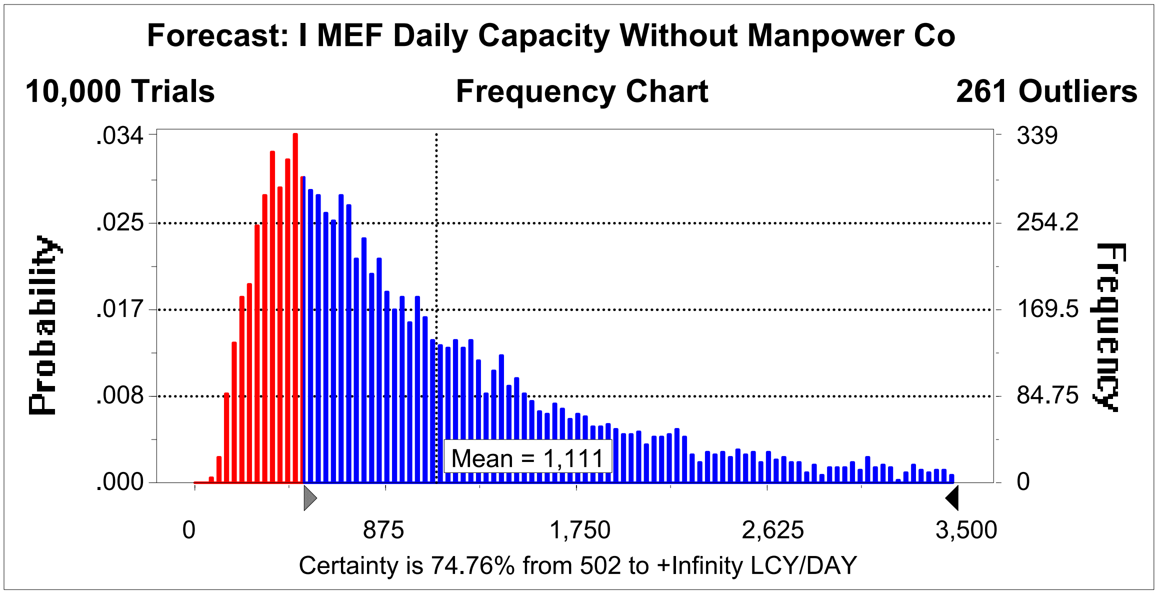

Figure 4-32: Scraper I MEF Capacity (Peacetime)

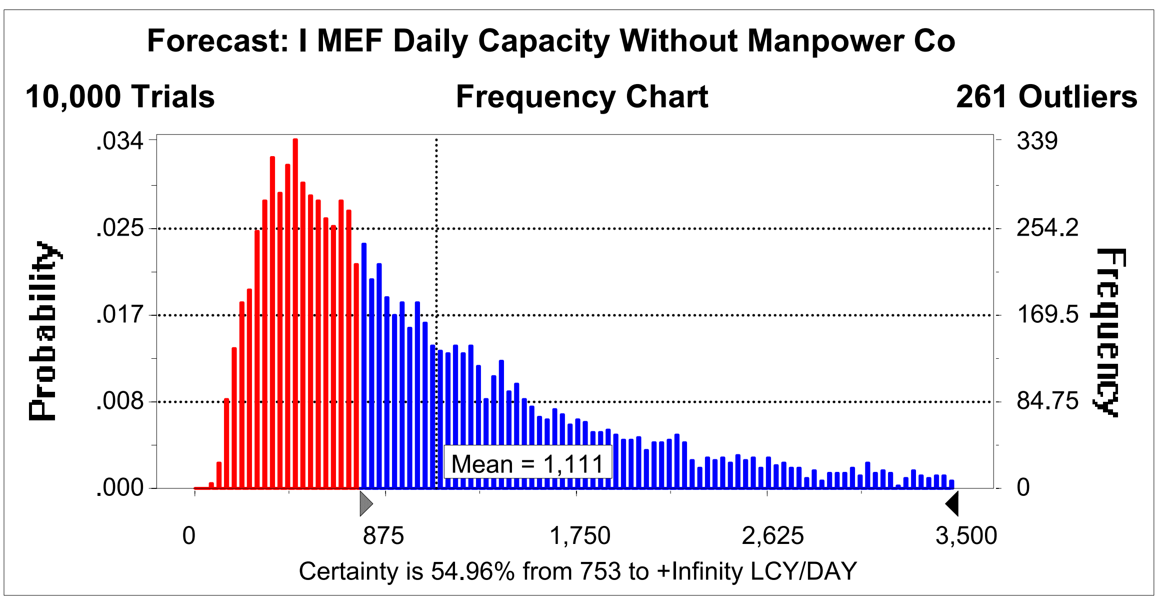

Figure 4-33: Scraper I MEF Capacity (Surge)

V. MILITARY AND CIVILIAN CONSTRUCTION STANDARDS

A. INTRODUCTION

The capacity model developed for this study can be used as a tool to calculate and compare actual to theoretical capacity of an engineer unit. This could be useful for evaluating the ability of a unit to meet a specific mission at a given point in time, given their current equipment readiness and operator availability levels, or to project a desired a capability given equipment and manpower constraints. Using civilian construction standards as a benchmark for the theoretically maximum capacity that a unit can achieve, the model can be used to determine and compare a unit's capacity based on military standards or to assess what is actually happening in the field. Armed with this information, a military planner can make an informed decision when determining the amount of equipment required by a unit for a given mission or scenario.

B. IMPORTANT CONSIDERATION

This chapter will discuss the more significant differences between civilian and military construction standards used for determining construction capacity and production levels. The discussion is important because actual capacity is influenced by many factors. These factors include differences due to the purpose of the organization and the type of work it plans for and the more obvious factors such as operator productivity and availability, which impact overall job efficiency. An understanding of why there are differences between civilian and military construction standards is critical to ensuring that valid results are obtained from the model. Discussion is also provided that addresses the results of the model when military production standards were applied.

1. Organizational survival and standards.

In the most basic sense, the production standards established by an organization are a means to its survival. For civilian entities, survival requires standards that will ensure profitability. For military organizations, survival may mean continued existence on the battlefield. The underlying goal results in different production standards. The difference in focus is obvious, but not always apparent when calculating what an organization should be able to do in terms of capacity. While a civilian project manager may consider and plan for potential difficulties to accomplishing a particular job that are similar to those encountered by military construction personnel, the military planner must also take into consideration the friction in war. Carl Van Clausewitz defines friction in war as an accumulation of negative factors that reduce the performance of a military force. [55] This difference reveals itself in various ways and requires sound judgment on the part of the planner or user of the model to adequately assess. This difference is incorporated into the model by the use of a *job efficiency* factor and will be discussed in more detail later in this chapter.

2. Specific job versus General Mission

Planning for a specific job versus a general mission is another key difference between military and civilian levels of production/capacity. A commercial construction company will gear up for a specific project to build, carefully selecting the equipment to be used so that it most effectively matches the requirement. Their choices are highly sensitive to and fluctuate with the economy. In contrast, a military organization is more concerned with having a generic equipment capability that meets a variety of needs.[56] Therefore, the military organization is dependent upon maintaining a certain capability regardless of its efficiency. It may have to use a larger dozer to accomplish what a smaller dozer might do much more effectively, or vise versa. This inefficiency is reflected in military production standards by use of job condition or site area productivity factors. Because military organizations typically must make do with the equipment they have on hand and do not always have the luxury of specifically selecting the most efficient equipment for a job at hand, military planner's should be aware that their capacity level cannot necessarily meet the ideal or most efficient that would be available with exactly the right equipment.

3. Operator Experience, skill and availability

Operator experience and skill can be critical to a commercial company's success on a job. To commercial enterprises, time is money, ensuring that civilian companies

[55] Clausewitz, Carl Von. *On War.* Princeton University Press. Princeton, New Jersey. 1976.

[56] Stark, James Reginald. *Analysis of Replacement Criteria for Naval Construction Force Equipment.* Naval Postgraduate School Thesis. March, 1975.

focus on maximizing the use of their equipment, and ensuring they have the best operators available. Civilian construction companies carefully train and cultivate their operators. According to a recent article in *Grading and Excavating Contractor* magazine, "Contractors who find good operators are unwilling to lose them…" and are willing to ensure their operator's are well trained to maximize production. Don Rhoads of Oftedal Corporation, headquartered in Montana is careful to note that "We're very thorough with our training. We have a big facility down in Casper, Wyoming, and we make sure that operators know how to run their machines for the best productivity."[57] As a result civilian standards typically reflect an 80% or better operator efficiency level. Use of apprentice equipment operators is carefully considered to minimize the impact of any reduced productivity. At the opposite extreme, military operators are generally inexperienced and developing their skills. As their skills progress and they promote, they move on to supervisory roles, creating a constant turnover of operators. This reduces the overall job efficiency for military operations and is reflected in lower productivity factors. Efficiency is certainly not as key a driver for military engineer units as it is for civilian entities.

Operator availability refers to how much time an operator is actually available to work at a job site, operating his machine in a typical work day. As compared to civilian employees, military personnel have fairly high administrative burdens placed on their time for such duties as physical fitness, medical and dental readiness, inspections and other administrative activities. This reduces their overall availability for operating equipment. One of the Naval Construction Force estimating guides recommends 67% as the baseline for the average available time for an operator on a specific job.[58] Whereas, civilian standards typically assume 50 minutes per hour, or an 80% availability factor for operators in an eight hour work day.[59]

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[57] Hull, Paul. *Grading and Excavating ContractorMagazine.* Forester Communications, Inc. 2001. www.forestor.net/gx_0011_skilled.html.

[58] Publication P-405 "Seabee Planner's and Estimator's Handbook." Naval Facilities Engineering Command. October 1994. Stock Number 0N 7610-LL-L26-6240

[59] Caterpillar Performance Handbook. Caterpillar, Inc. Peoria, IL.

C. SPECIFIC COMPARISONS OF STANDARDS

1. Standards used

This section discusses the three specific construction standards used in this study. They include standards established by a major construction equipment supplier in the civilian construction industry and two major military construction organizations. The primary references used for discussion are Caterpillar's Equipment User's Guide, U.S. Army Field Manual FM 5-100 "Engineer Operations" and FM 5-434 "Earthmoving Operations" (referred to as the guiding reference for USMC construction estimating in the Marine Corps War Fighting Publication (MCWP 3-17) "Engineering Operations"), and the Naval Construction Force (NCF) standard, Naval Facilities Engineering Command's P-405 "Seabee Planner's and Estimator's Handbook" (NAVFAC P-405).

2. Civilian Standards

As discussed in the chapters on model development, each MEF's current equipment readiness and operator availability were used to calculate a baseline for the number of pieces of usable equipment. The number of pieces of usable equipment was then used to determine a total capacity level by applying appropriate production factors to the equation for total capacity. The capacity equation used is: Hourly Capacity = (Correction factors + task factors) x Maximum Equipment Production capacity (based on equipment characteristics). Caterpillar's production estimating standards were used as the benchmark for the maximum theoretical capacity for any given scenario.

a. Why choose civilian standards?

Civilian construction companies exist to make money. To maximize profits they need to maximize productivity and minimize costs. By studying local civilian heavy construction companies we were able to determine how they achieved these goals, thus establishing a benchmark to compare military productivity standards and costs over the life cycle of the equipment.

Interviews were arranged to determine: procedures for job estimates, maintenance schedules, lifecycle cost determinants, phased replacement procedures, and surge support plans. We soon found that local construction companies' operations are base on personal experience with minimal data analysis. "Pretty much everything we do is by intuition".[60] This did nothing to establish our benchmark.

b. Why choose Caterpillar as an example?

As discussed in chapter two, the USMC has established a Required Operational Capability (ROC) for each piece of equipment in our study. Each ROC identifies a model from the Caterpillar Inc.: Heavy Motorized Road Grader (130G)[61], Light Crawler Tractor (D6C)[62], Heavy Crawler Tractor (D7G)[63], and Earth Scraper (621B)[64]. While the preferred Light Crawler Tractor is the Case 1150 the Caterpillar D6C is listed as a viable alternative. By evaluating each type of equipment within one company we were able to focus our research to determine production specifications and life cycle costs. We utilized data collected by Caterpillar in establishing our civilian benchmark.

Caterpillar Inc. has a history of doing business with the USMC, as well as other government entities. To meet the specific needs of the federal government they have created a Defense and Federal Products Division and established a contract with the Government Service Agency (GSA)[65].

3. Military Standards

Table 5-1 provides an overview of the basic differences between the NCF, Army and civilian standards when applied to dozing operations.

An analysis of the standards reveals that the factors related to equipment characteristics are very similar for the three standards. For example, all three standards used the same equation for determining a weight correction factor, and only minor differences were found in the soil characteristic tables provided in each reference.

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60 Scott, Vern. PAVEX Construction Company. Watsonville, CA, March 17, 2003.

61 ROC, Heavy Motorized Road Grader. USMC, September 29, 1996.

62 ROC, Light Crawler Tractor, USMC, March 23, 1982.

63 ROC, Heavy Crawler Tractor, USMC, October 10, 1976.

64 ROC, Scraper, USMC, date.

65 http://www.gsaelibrary.gsa.gov/elib/ContractorInfo.jsp?contractNumber=GS-30F-1025D&contractorName=CATERPILLAR+INC&executeQuery=YES

Similarly, correction factors for grade and dozing style were common to all three standards. However, significant differences between the standards were found for operator skill, job efficiency and operating conditions. Although each reference provides a range of values for each of these factors based upon some of the issues previously

Correction Factors	Definitions	Civilian Standards	Army Standards	NCF Standards
Maximum Production (LCY/Hr)	Based on either an equation, table or chart for the type of equipment and linear feet to be dozed.	Max Production = 13350 x Avg Dozing Distance^-.6823	Army uses a chart based on average dozing distance and type of dozer.	NCF uses a chart based on avg dozing distance and type of dozer.
Weight Correction	Based on an equation which incorporates the actual material weight	Equals 2300 lbs per LCY/actual lbs per LCY Actual material weight obtained from a chart	Same equation. See Army Table for actual material LCY weight.	Same equation. See NCF Table for actual material LCY weight.
Cutting Difficulty	This refers to the type of soil to be moved. Loose, sticky, rock, clay, etc.			
Loose		1.2	1.2	Not addressed in the NCF reference.
Cohesive, Frozen, or Sticky		0.8	.7 to .8	
Rock (Ripped or Blasted)		0.6	.6 to .8	
Grade Correction Factor	If the grade is positive, this factor will be < 1.0. If the grade is negative, > 1.0.	[%grade times (-0.021536)] + 0.985714	The Army uses a graph. Values are slightly difference from civilian. See Figure B-1 in Appendix B.	Not addressed in the NCF reference.
Slot/Side by Side Correction	This refers to the type of bulldozing. Are passes side by side or is the dozer building a trench type of excavation (slot).	Slot = 1.2 Side by Side = 1.15 to 1.2	Slot = 1.2 Side by Side = 1.15 to 1.25	Slot = 1.25 Side by Side = 1.0
Job Efficiency Factor	Based on various factors and judgment	[0.000714286 + 0.016642857] x Operator Efficiency	Based on Op skill and whether work is during the day or night. See Table 5-3.	Based on several factors. See Table 5-2.
Operator Skill Level	Based on training and experience	Typically 80% or better	Judgment	Judgment
Operating conditions	This includes such factors as weather, whether the job site is confined, accessibility, etc.	Judgement	Based on operating zones. See Table B-1 in Appendix B.	low/average/high See Table 5-3.

Table 5-1: Comparison of Production factors for the D7G Dozer

discussed, these three factors represent the most significant differences when estimating capacity because they are determined by the experience and judgment of the person evaluating the work to be done. While all three standards addressed these factors as important in determining production capacity, the NCF standard was the most descriptive as to their impact on overall production.

The NAVFAC P-405 defines seven specific equipment productivity factors that must be considered when estimating equipment production. They include permissible speeds of the equipment, the type of material to be handled, safety factors, operator experience, age and condition of equipment, required completion time and climate. The tabular values provided in the P-405 for estimating production must be adjusted to fit the conditions expected on each project. The NCF also provides descriptive guidance in determining job efficiency and operating conditions. Table 5-2 summarizes the values used by the NCF to evaluate foreseen conditions and determine production efficiency factors.

NCF Production (Job) Efficiency Factor (P - 405 Table 4-1)			
	Low Production	**Average Production**	**High Production**
Percentage	25 35 45	55 65 75	85 95
Workload	high	average	low
Site Area	cramped/poor	limited space/avg laydown and access	large work area/good laydown and access
Labor	poorly trained/motivated or inexperienced	adequately trained/motivated/experienced	highly trained/motivated and experienced
Supervision	inexperienced and low training	average experience and training	highly trained/motivated and experienced
Job Condition	short fused/high quality required	avg quality/adequate time allotted for the job	well planned job/only rough /unfinished work required
Weather	abnormal/hot/rain/cold	moderate	favorable
Equipment	poor condition/maintenance/wrong application	fair condition	good condition/right application
Tactical/Logistical	slow supply/requent delays	normal supply, few tactical delays	good supply, no delays

Table 5-2: NCF Production Efficiency Factors

The estimator evaluates each element given in the Table at some percentage between .25 and 1.00, and then an average of the eight elements is used as the overall production efficiency percentage. While the NCF uses this chart specifically to estimate man-day capabilities, it is useful as a guide for evaluating the different conditions that will affect job efficiency[66]. This table was used as a generic guide to determine an appropriate military job efficiency factor for use in the model.

The Caterpillar Equipment User's Guide and the Army's Field Manual also addressed these three key factors. Both stated that job efficiency should be determined by considering the impact of such factors as site location, working conditions and time requirements of the job (day or night work). Both recommended typical values between 60 and 80%. Table 5-3 is the guide used by both the Army and USMC in evaluating Operator Efficiency. The NCF standard seems most applicable to apply to a military situation that involves planning for a generic capacity level.

TYPE UNIT	OPERATOR	DAY	NIGHT
	EXCELLENT	1.OO	0.75
TRACKED	AVERAGE	.75	.56
	POOR	.60	.45
	EXCELLENT	1.OO	.67
WHEELED	AVERAGE	.6O	.4O
	POOR	.5O	.33

Table 5-3: Operator Efficiency

These same three factors affected the capacity levels for the other two classes of construction equipment evaluated in this study (graders and scrapers) as well, but we had to change the methodology to apply the standards as provided in the references. This was due to how the standards for determining capacity were given in the reference. For example, for graders, the NCF reference provided a generic table that listed an hourly production rate based on historical commercial equipment guides instead of providing specific technical factors based on equipment characteristics. The model itself was

66 Publication P-405 "Seabee Planner's and Estimator's Handbook." Naval Facilities Engineering Command. October 1994. Stock Number 0N 7610-LL-L26-6240

developed using the Caterpillar Equipment User's Guide and incorporates the technical equipment characteristics of the specific equipment in use.

D. APPLICATION OF STANDARDS TO THE CAPACITY MODEL

1. Methodology

Using the references discussed above, we were able to obtain an estimate of the magnitude of differences in estimating earthmoving capacity between civilian and military construction organizations. Essential to the calculations was to ensure that we compared equivalent pieces of equipment. Each piece of Caterpillar equipment that the model was based on was cross-referenced with NCF, USMC and Army equipment. Similarly, to ensure consistent application of the standards, a specific set of "job conditions" was developed. For example, the same length of road to be graded, type of soil to be cut and blade angle were used to calculate capacity using a given standard. Then military or civilian standards were applied to those factors that allowed for the Planner or Project Manager's input based on judgment or experience.

2. Results

The analysis supported our expectation that civilian standards generally result in a much higher production capacity than military standards. Table 5-4 provided below shows the results for each of the pieces of gear analyzed. It is extremely important to note that the results shown in the table are for one specific scenario and are based on the various assumptions made by the team in applying the standards. The results are not meant to indicate or infer that one set of standards is better than another or that military personnel are not capable of higher production. However, the results do show that the operational differences between civilian construction industry and military construction organizations are significant and should be taken into consideration when making assumptions about production capabilities. The capacity level of a unit depends more on the operator's than the equipment itself. The difference between the standards is provided for information and should be of use to Marine Corps planning and decision making personnel who may use the model to determine the current capacity of USMC engineer units or for making inventory objective determinations.

	Civilian	Army	NCF
D7G Dozer	467 LCY/hr	239 LCY/hr	193 LCY/hr
Motor Grader	0.95 mi/hr	0.33 mi/hr	.11 mi/hr or .35 mi/hr
Scraper	62 LCY/hr	74.5 LCY/hr	43 LCY/hr

Table 5-4: Capacity Comparison

**Disclaimer statement: Table values are based on specific assumptions for very specific scenarios. Different assumptions will greatly change the results.

3. A few general comments on standards.

The Army Field Manual followed a rigorous, technical approach based on specific equipment characteristics to estimate production of its earthmoving operations. In contrast, the NCF Estimating Guide provided tables based on average commercial manufacturers and government planning sources, adjusted to NCF productivity. The tables incorporated the technical calculations into its values for ease of use by its planning and estimating personnel. For example, for Scraper operations, the NAVFAC P-405 provided a simplified table to determine the quantity of soil that could be moved per hour based on scraper size and haul distance. The table values incorporated technical calculation factors of rolling and grade resistance, rim pull required and travel speed which were required to be calculated using the other two reference standards.

E. SUMMARY

It is important to note the difference in purpose and mission of each of the standards used. Civilians use their standards to cost out a job and are careful to ensure they don't underbid. Therefore their standards will allow a certain comfort level that is acceptable to the company, but that is still significantly lower than that allowed for military organizations. USMC equipment is equivalent to those evaluated in the standards. The USMC uses Army Field Manuals as their technical field manuals for engineer operations. Users of the model should consider carefully best and worst case scenarios when assessing capacity of USMC units.

The potential to base target inventory objectives on the results of the model provided in this study is high, but each of the issues discussed in this chapter should be carefully considered. Unfortunately data for evaluating whether the current USMC T/E inventory levels are sufficient to meet current operations was beyond the scope of this study, but this is an area that provides a rich opportunity for further study. If the desire is to ensure construction capability meets operational requirements, I&L should solicit a study to develop a methodology for determining inventory objectives based on a defined set of potential construction mission scenarios that correspond to the most current Required Operational Capabilities for Operational Contingency Plans. This information could then be used as a baseline for analysis of current capacity versus required capacity.

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VI. LIFE CYCLE MANAGEMENT

A. INTRODUCTION

One of the questions we were asked to address was whether the USMC could improve its Life Cycle Management. This chapter addresses the current practices in use by the civilian construction industry and military construction organizations.

B. OVERVIEW OF LIFE CYCLE COSTING

1. Life Cycle Costs

Life cycle costing is "the total costs of ownership over the life span of an asset"[67] and should be used when the asset will require substantial operating and maintenance costs over a significant life span. Total costs of ownership include the asset's purchase price and all significant expected costs. Using the following formula allows us to begin estimating the life cycle costs of construction equipment:[68]

$$L_{ccc} = AC_c + \sum_{i=1}^{NL} (SMC_i + OC_i + URC_i) + DC$$

Where:

- L_{ccc} is the total life cycle cost of the equipment.
- AC_c is equipment acquisition cost.
- NL is the equipment life span.
- SMC_i is the scheduled maintenance costs.
- OC_i is the operating costs.
- URC_i is the unscheduled maintenance costs.
- DC is the disposal costs.

Maintenance (SMC_i and URC_i) costs can further be broken down into the cost of: facilities, requirements for special tools, repair parts, labor of the maintainers, labor for training, equipment inventories, publications, and technical manuals used for the

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67 R.J. Brown and R.R. Yanuck, Introduction to Life Cycle Costing, Fairmont Press Inc., Atlanta, GA, 1985, pg 1.

68 B.S. Dhillon, Life Cycle Costing Techniques, Models and Applications, Gordon and Breech Science Publishers, New York, 1989, pg 67.

maintenance.[69] Further cost considerations for URC_i can be estimated by using the following formula:

$$URC_i = (T_{so}) * (MLC) * \left[\frac{MTTR}{MTBF}\right]$$

Where:

- T_{so} is the scheduled operating hours.
- MLC is the hourly maintenance labor cost.
- MTTR is the mean time to repair.
- MTBF is the mean time to failure.

Operating costs consist of: labor costs of operators and fuel costs.

2. Equipment Life Expectancy

An asset's life span begins with the purchase and ends when total average annual costs are minimized. To estimate the life span, we must first prepare an asset trade-in schedule and maintenance and repair schedule. Trade-in schedules list estimated resale values for each year of ownership. Maintenance and repair schedules list all costs associated with corrective and preventative maintenance over the same period. These schedules can be combined to calculate total average annual costs. The service life ends when the average annual costs are at a minimum.[70]

3. Time Value of Money

Life cycle costs cannot be determined without considering the time value of money. Determining the present value of money that will be spent in the future, or that has been spent in the past, is called discounting. This process facilitates the translation of all values into present values. "All life cycle cost analysis must be performed in terms of compatible dollars".[71]

C. CIVILIAN CONSTRUCTION INDUSTRY LIFE CYCLE COSTING

[69] B.S. Dhillon, Life Cycle Costing Techniques, Models and Applications, Gordon and Breech Science Publishers, New York, 1989, pg 131.

[70] R.J. Brown and R.R. Yanuck, Introduction to Life Cycle Costing, Fairmont Press Inc., Atlanta, GA, 1985, pp 95-96.

[71] R.J. Brown and R.R. Yanuck, Introduction to Life Cycle Costing, Fairmont Press Inc., Atlanta, GA, 1985, pg 15.

1. Caterpillar, Incorporated

Now that we have an understanding of the general life cycle costing principles let us take a look at how Caterpillar Inc. performs life cycle costing. Chapter 22 of the Caterpillar Performance Handbook, Edition 31 is titled: Estimating Owning & Operating Costs. They begin the chapter by stating that owning and operating costs can vary widely for each machine. These costs are influenced by factors such as: type of work the machine is performing, fuel prices, operator and maintainer wages, etc. The handbook does not attempt to provide precise costing methods; they merely suggest methods to estimate hourly owning and operating costs.[72]

2. Detailed Estimating

The first method provides an estimating form shown in Figure C-2 in Appendix B. The form is a three page, detailed estimating guide that provides space for side-by-side comparison of different equipment models. Ownership periods of Caterpillar are given in operating hours based on application and operating conditions. These periods are given in the following table:

3. Quick Estimating

The Caterpillar Performance Handbook also provides a quick estimator based on the following assumptions[73]:

- List prices f.o.b. factory.
- Machines are equipped as indicated.
- Ownership period follow guide provided.
- The basic repair factors are based on the first 10,000 hours of service.
- Parts at published U.S. Consumers List Prices.
- Labor for repairs at total selling price of $50.00 per hour.
- MODERATE: Zone A, or moderate job conditions.
- AVERAGE: Zone B, or average job conditions.
- SEVERE: Zone C, or sever job conditions.
- Lubricants and hydraulic oil at $6.35 per U.S. Gallon plus labor.
- Grease at $0.71 per fitting (includes labor).
- Filters at U.S. Consumer's List Prices plus labor.

[72] Caterpillar Performance Handbook, a CATERPILLAR publication by Caterpillar Inc., Peoria, Il, pg 22-1.

[73] Caterpillar Performance Handbook, a CATERPILLAR publication by Caterpillar Inc., Peoria, Il, pg 22-50.

- Fuel at $1.25 per U.S. Gallon.
- All figures exclude interest, insurance, taxes and operator.

EQUIPMENT	ZONE A MODERATE	ZONE B AVERAGE	ZONE C SEVERE
TRACK TYPE TRACTORS	Pulling scrapers, most agricultural drawbar, stockpile, coal pile. No impact. Intermittent full throttle operation.	Production dozing in clays, sands, gravels. Push loading scrapers, borrow pit ripping, most land clearing applications. Production landfill work.	Heavy rock ripping. Push loading and dozing in hard rock. Work on rock surfaces. Continuous high impact conditions
D5M-D6M	15,000 HR	12,000 HR	NA
D6R-D7R	20,000 HR	15,000 HR	10,000 HR
MOTOR GRADERS	Light road maintenance. Finishing. Plant and road mix work. Light snowplowing. Large amounts of traveling.	Haul road maintenance. Road construction, ditching. Loose fill spreading. Land forming, land leveling. Summer road maintenance with medium to heavy winter snow removal. Elevating grader use.	Maintenance of hard packed roads with embedded rock. Heavy fill spreading. Ripping-scarifying of asphalt or concrete. Continuous high load factor. High impact.
120H-16H	20,000 HR	15,000 HR	12,000 HR
WHEEL TRACTOR-SCRAPERS	Level or favorable hauls on good haul roads. No impact. Easy-loading materials.	Varying loading and haul road conditions. Long and short hauls. Adverse and favorable grades. Some impact. Typical road-building use on a variety of jobs.	High impact condition, such as loading ripped rock. Overloading. Continuous high total resistance conditions. Rough haul roads
621G-627G	22,000 HR	17,000 HR	12,000 HR

Table 6-1: Caterpillar Inc Equipment Ownership Periods

EQUIPMENT		ZONE A MODERATE	ZONE B AVERAGE	ZONE C SEVERE
D6G	HOURLY	$23.00	$30.00	$50.00
	LIFE CYCLE	$345,000.00	$360,000.00	$500,000.00
D7G	HOURLY	$32.00	$41.00	$63.00
	LIFE CYCLE	$640,000.00	$615,000.00	$630,000.00
140H	HOURLY	$22.00	$26.00	$33.00
	LIFE CYCLE	$440,000.00	$390,000.00	$396,000.00
621G	HOURLY	$40.00	$53.00	$83.00
	LIFE CYCLE	$880,000.00	$901,000.00	$996,000.00

Table 6-2: Quick Estimator Owning and Operating Costs

The values listed in Table 6-2 are operating and maintenance costs and do not include equipment purchase prices, interest, insurance, and taxes.

4. Summary

Life Cycle Costing in the civilian sector is based upon accounting practices of the particular firm, its manager's experience and judgment, and has profit related impact. LCC is standard business practice for civilian firms and has been used by many to make capital investment decisions. However, within the Department of Defense, LCC and its use for making investment decisions is a relatively new initiative.

D. DEPARTMENT OF DEFENSE LIFE CYCLE MANAGEMENT

Reports by the GAO from the 1980's indicate that DoD placed little emphasis on the total cost of ownership, even though these costs can easily amount to more than the initial acquisition cost.[74] The subsequent, long term operating and maintenance costs of systems were not considered a part of the procurement decision. However, the next decade's funding reductions forced the military to reevaluate the impact of these costs in relation to procurement decisions when fielding systems. Secretary of Defense William S. Cohen announced in 1997 that reducing the Total Ownership Cost (TOC) for our Defense systems not only made good sense but was the only way that the Department of

[74] United States General Accounting Office, "Defense Acquisitions: Higher Priority needed for Army Operating and Support Cost Reduction Efforts", GAO/NSIAD-00-197, September 2000.

Defense (DoD) would be able to afford to sustain and modernize its weapon systems in the near future."[75] Subsequently, the Under Secretary of Defense for Acquisition &Technology (USD A&T) issued a memorandum for the Secretaries of the Military Departments that defined DoD TOC in defense terms as "the sum of all financial resources necessary to organize, equip, sustain, and operate military forces sufficient to meet national goals in compliance with all laws, all policies applicable to DoD, all standards in effect for readiness, safety, and quality of life, and all other official measures of performance for DoD and its components."[76]

The memorandum also identified the role and responsibility of Defense Program Managers (PMs) for reducing DoD's TOC by reducing the Life Cycle Costs for their systems. For DoD, TOC is equal to Life Cycle Cost (LCC)[77]. Before the issuance of USD (A&T)'s guidance, procurement and sustainment of systems were viewed and managed separately, with no formal requirement for accountability or consideration of total system costs during procurement. USD (A&T)'s memorandum therefore, initiated a fundamental change in how PM's viewed and managed the funding stream for their programs. PMs were now responsible for managing direct costs for their acquisition programs from Research & Development through disposal. The result has been a concerted effort by all the services to incorporate life-cycle management into procurement decisions and to reduce the portion of funds related to sustainment, commonly known as Operating and Support Costs (O&S).

E. USMC AND LIFE CYCLE COSTS

Marine Corps Systems Command (MARCORSYSCOM) is the Program Management organization responsible for the heavy construction equipment under review in this study. They have begun implementing formal life cycle costs as part of their management of USMC construction equipment and they estimate life cycle costs as a

[75] http://pmcop.dau.mil/simplify/ev.php. History of Total Ownership Cost (TOC), Formal initiation of Reduction of TOC, July 10, 1997

[76] Gansler, J. S. "Definition of Total Ownership Cost (TOC), Life Cycle Cost (LCC) and the Responsibilities of Program Managers", Memorandum for Secretaries of the Military Departments, 13 November 1998.

[77] DoD 5000.4M

"combination of up front or procurement costs for an alternative and an estimate of the total ownership costs for a full ten year life cycle." [78] The equation is: **LCC = Acquisition Cost + O&S Costs**. This equation is similar to that discussed above for civilian LCC, however, a major difference is the basis used for the equipment's life expectancy. The military has historically based the total life cycle of its heavy construction equipment on a life expectancy defined in years, whereas civilian industry typically defines equipment life in hours of use. This represents a major difference in methodology between military and civilian treatment of their equipment.

The use of setting a life expectancy in years is common across the services and was established before the concept of life cycle management emerged. The impact of using years as the sole criteria for procurement and replacement decisions should be obvious. If procurement decisions are based solely on a ten-year life expectancy then there is the potential to dispose of equipment that has been used very little and is still in good condition. Due to funding constraints over the last several years, each service has also developed other criteria beyond the simple life expectancy for determining the correct disposition of a piece of equipment when it comes up for review. Life expectancy in years is now being used as a screening tool for reviewing the use, condition and technological currency of the equipment during the POM cycle.

F. LIFE EXPECTANCY DETERMINATION AND ITS IMPACT ON LCC

This section provides a simple review and analysis of the life expectancies established by the USMC and the Naval Construction Force (NCF) for their heavy construction equipment. This was important in order to assess if there are any best business practices within the services and to see how they compared to commercial practices.

1. United States Marine Corps

Sometime in the past, a generic life expectancy of ten years was established by the USMC for all pieces of equipment considered part of the core line of equipment defined as the "Family of Construction Equipment". This number currently forms the

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[78] Marine Corps System Command, Ground Transportation And Engineer Systems Business Case

basis in which equipment is evaluated for disposal and drives procurement decisions for the POM. There was no definitive historical knowledge for how this standard was initially established, but it is assumed that it was based upon manufacturer's recommendations and the projected operational environment. Currently, the USMC uses the ten-year standard as a starting point for evaluating equipment readiness and setting acquisition objectives for the POM cycle. Equipment purchased for the Marine Corps is documented upon acquisition and when it reaches the ten-year mark it is reviewed in terms of the current required operational capabilities (ROC) document, state of technology, and continued availability of parts. Unfortunately, reliable data on the actual use and condition of the equipment is not readily available to those making the procurement decisions. The only documented source of O&M costs for the equipment is the Marine Corps Integrated Maintenance Management System - Automated Information System (MIMMS-AIS). However, the data compiled in the MIMMS-AIS fails to capture many of the O&S costs associated with pre-expended bin items, non-system NSNs (Local NSNs) and open/credit card purchases. Uniform labor costs of Marines in the field are captured in MIMMS-AIS, however, labor hours are understated because of MIMMS-AIS system limitations. Repair Issue Points (RIP) (Secondary Repairable) asset costs and Class IX repair parts supporting real world contingency and major exercises are also not captured in MIMMS-AIS.[79] Although this data maybe maintained at the local unit level, it is not being systematically captured. Additionally, there is no formal mechanism for units to provide input into the procurement or replacement decision in terms of each individual piece of equipment. Although the operating forces are represented on the Integrated Product Teams which are reviewing procurement decisions in terms of future requirements dictated by the USMC's 21st Century Strategic Vision, there is no formal review of the actual condition of the equipment in the field or its use.[80]

Analysis For Replacement Of The Small Emplacement Excavator (See), April 2003.

79 Business Case Analysis for the EBFL. MARCORSYSCOM. 20 Dec 2000.

80 Farley, Mike. Project Officer, Marine Corps Systems Command, Quantico, VA. Telephonic Interview, 8 May 2003.

One of the latest initiatives underway in the Marine Corps is the elimination of propositioned war stock of construction equipment. This allows for lower acquisition objectives and should result in lower overall life cycle costs.

2. Naval Construction Force

Construction equipment for the NCF is managed by the Civil Engineering Support Office located at the Construction Battalion Centers (CBC) in Gulfport, Mississippi and Ventura Naval Base, Port Hueneme, California. The NCF tracks the acquisition and location of its equipment in a central database called CASEMIS. Similar to the USMC, actual use, maintenance costs and condition of the equipment is tracked at the local unit level and is not collected in any central information system.

Life expectancies for the NCF equipment have been established in years based upon manufacturer's recommendations and projected operational environment[81]. For the equipment in this study, NCF life expectancies were longer than the USMC standard of ten years. This could be the result of the initial assumptions made by those managing the USMC equipment. It seems reasonable that the shorter life expectancy set by the USMC was based on an assumed operating environment for Marine Corps Combat Engineers that would be more severe than that for the NCF units. However, replacement decisions for NCF equipment are also based upon a biennial review of the actual use and condition of the equipment. NAVFAC Instruction 11200.35B requires CBC to send a comprehensive equipment report to all units. The report highlights equipment that is up for review based on its life expectancy and requires the unit to provide input to the CBC about the actual use, condition and maintenance costs of the piece of gear. Decisions are funding driven and based upon both the life expectancy criteria and data provided by the using unit. One of the advantages used by CBC in managing the equipment for the NCF is the availability of equipment maintained in the Prepositioned War Reserve Material System (PWRMS). CBC meets immediate needs for equipment by rotating stock out of the PWRMS, replacing it with newly procured equipment resulting in a refreshed and updated PWRMS.

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[81] Laszik, John. Construction Battalion Center, Port Heuneme, CA. Telephonic Interview, May 2003.

G. LIFE CYCLE ANALYSIS

1. Net Present Value

One of the questions we had for this study was whether the USMC could improve its Life Cycle Management by changing the basis of how it calculates Life Cycle Costs. MARCORSYSCOM has already begun implementing LCC into its procurement decisions based on the 10-year life expectancy. Because LCC is based upon the life expectancy of the equipment, we first researched and evaluated how the USMC sets its life expectancy, as well as how civilian industry and other military organizations determine it in order to search for best business practices or commonality between methodologies. As discussed above, the commonality was found to be that military organizations establish life in years, whereas, civilian industry typically uses hours of use.

To fully answer the question as to whether the USMC could or should change the basis of their Life Cycle Management, we performed a simple Net Present Value Analysis of alternatives. This procedure was used because it is "The standard criterion for deciding whether a government program can be justified on economic principles…".[82] Although we were unable to perform a true cost-benefit analysis (because of the lack of data), we were able to determine if it was cost effective for the USMC to change their life cycle management from a ten year life cycle to a 20 year life cycle. Cost effectiveness analysis is appropriate whenever it is unnecessary or impractical to consider the dollar value of the benefits provided by the alternatives under consideration.[83] OMB circular A-94 further provides guidance that a program is cost-effective if, on the basis of *life cycle cost* analysis of competing alternatives, it is determined to have the lowest costs expressed in present value terms for a given amount of benefits. Table 6-3 provides the results of the NPV analysis using the USCOE tabular values for evaluating LCC.

[82] Office of Management and Budget; Circular A-94. Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs; United States Government, 29 October 1992.

[83] Office of Management and Budget; Circular A-94. Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs; United States Government, 29 October 1992.

Net Present Value Analysis of Life Cycle Alternatives		
Equipment	**10 yr Life**	**20 yr Life**
Scraper	$1,683,963	$1,477,814
Motor Grader	$522,689	$463,126
D7G Dozers	$934,756	$800,872
1150 Crawler	$508,216	$443,146

Table 6-3: Net Present Value

To construct the table we began with the acquisition price of the equipment as given in the USACOE Construction Equipment Ownership and Operating Expense Schedule. Determination of annual O & M costs are given below. At the 10-year point a decision had to be made, buy or extend. Under the 10-year life column we added the acquisition cost of a new piece of equipment. Under the 20-year life column we added in the cost of a Service Life Extension Program (SLEP). This cost was assumed to be 35% of the acquisition cost.[84] Costs of both equipment were spread out over 20 years and discounted at 6%.

The results show that for all cases the NPV for a longer life cycle is a lower value, which indicates that the use of a longer life cycle is a promising business choice for the USMC. This analysis is supported by the fact that the existing equipment inventory is currently well beyond the ten year life expectancy. The average age of the USMC D7G inventory is 16 years and for the 1150 crawler scrapers it is 12 years. An extension of the initial life cycle for the equipment can result in an overall reduction in total life cycle costs to the government of approximately 20%. As long as the equipment does not become obsolete, and with the potential to prolong the equipment's life even longer using the Service Life Extension Program (SLEP), the government could easily increase its return on investment in its construction equipment inventory.

2. Sources of Equipment Costs

We were unable to obtain any reliable data on actual maintenance costs for USMC equipment. Therefore, all of our calculations were based on public sources of

[84] Abbreviated Business Case Analysis on the Scraper, Tractor, 621B, dated 3 January 2001

tabulated data. The three primary sources we used for comparison were the Caterpillar Performance Handbook, The Army Corps of Engineers Construction Ownership and Operating Expense Schedule, and the Contractor's Equipment Cost Guide. Each of the references listed provide an average hourly O&S rate over the life of the equipment that incorporates ownership and operating cost factors such as depreciation, facilities capital cost of money, fuel, consumables such as filters oil and grease, repairs and tire wear and repair. The table below indicates typical values obtained from these sources.

Hourly rates vary widely depending upon the assumptions made in the reference. Previous studies of actual average costs calculated for NCF heavy construction equipment has ranged from $74.26 to $168. For the Net Present Value analysis of Life Cycle Costs, the USACOE reference values were used.

Equipment		Contractor's Equipment Cost Guide	Caterpillar's Performance Handbook	USACOE Construction Equipment Ownership and Operating Expense Schedule
621F Scraper	Approximate Base Price	$429,910	NA	$456,654
	Hourly Rate	$151	$53	$89
135H Grader	Approximate Base Price	$180,150	NA	$193,621
	Hourly Rate	$47	$26	$35
D7R	Approximate Base Price	$322,690	NA	$325,026
	Hourly Rate	$107	$46	$57

1. 1998 values are provided in the references
2. D7R dozer used for comparison. Not all references contained values for the D7G.

Table 6-4: Cost Comparisons

3. Cost of Money

The discount rate used for all analysis is the projected real discount rate outlined in the Office of Management and Budget's Circular No A-94. [85] This figure incorporates projected inflation rates. Additionally, our analysis assumed zero growth for future costs.

4. Relationship between LCC and Use

The NPV analysis and LCC were calculated with assumed values of use. For the Scraper, the annual hours of use were assumed to be 813 based upon the most recent data available from MARCORSYSCOM.[86]

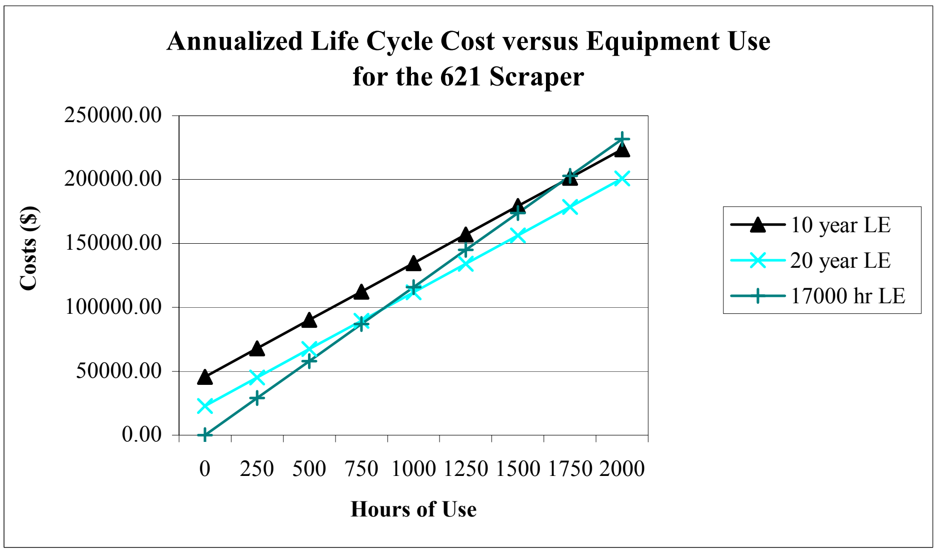

Figure 6-1: Annualized Life Cycle Cost

The chart shows the relationship between annualized LCC and hours of use of the equipment (LCC are calculated for a single piece of equipment.). As expected, if the life expectancy (LE) is longer, annualized LCC are lower. However, our analysis of annual operating costs is based on assumed usage of the equipment. If actual use of the

[85]Office of Management and Budget; Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs; United States Government, 29 October 1992

[86] MARCORSYSCOM, Combat Support and Logistics Equipment Branch. *Abbreviated BCA for the Scraper, Tractor 621-B.* 3 Jan 2001.

equipment is significantly higher, then a shorter life expectancy and higher costs will be the result. The chart shows that if hours of use are used as the basis for life cycle costs, then as the quantity of use increases, the LCC increase at a greater rate.

In addition to considering actual hours of use, military planners must take the operating environment into account. The values used in our analysis were based upon average operating conditions. For severe operating conditions, life expectancies are much lower and hourly O&S costs are much higher. Refer to the any of the references discussed earlier for approximate values to use for those conditions.

5. Procurement Plans

One of the major determining factors in equipment management that we have not discussed is procurement plans. Procurement plans are a major cost driver in determining the total LCC of an equipment fleet. Program Managers must evaluate as many options as possible to meet their funds available. An extension in life cycle for the equipment should allow Project Managers to reduce the total number of new equipment required in each POM cycle.

6. Limitations

This study provides a very simplistic evaluation of two alternatives to life expectancy. The impact of war, attrition of equipment and cost creep have not been discussed but should also be taken into account in total life cycle management policy.

H. SUMMARY

Because the actual use of their equipment is reasonably low, the USMC should base its LCC on hours of use instead of years. The use of hours as the basis for life cycle is consistent with civilian industry practices. However, because it is difficult to track actual hours of use and incorporate it into the life cycle management process, an alternate recommendation is for the USMC to extend the initial life cycle of their equipment to 20 or more years, depending upon the type of equipment and its actual use. Tables 6-5, 6-6, and 6-7 provided below are a summary of the values used for calculating the NPV. The data shows that the USMC would be justified in using a much longer life expectancy for their equipment.

621F Scraper Average Operating Conditions			
Constant 1998 $	**10 yr Life**	**20 yr Life**	**17000 hr Life**
Assumed Annual hours of use	813	813	813
Life Expectancy (yrs)	10	20	20.9102091
Life Expectancy (hrs)	8130	16260	17000
Acquisition Cost	$456,654.00	$456,654.00	$456,654.00
Hourly O&M Cost	$89.00	$89.00	$89.00
Annual O&M Cost	$72,357.00	$72,357.00	$72,357.00
Life Cycle O&M	$723,570.00	$1,447,140.00	$1,513,000.00
Total LCC	$1,180,224.00	$1,903,794.00	$1,969,654.00
Annualized LCC	$118,022.40	$95,189.70	$94,195.81

Table 6-5: Scraper Life Cycle Cost Analysis

35H Motor Grader Average Operating Conditions			
Constant 1998 $	**10 yr Life**	**20 yr Life**	**15000 hr Life**
Assumed Annual hours of use	400	400	400
Life Expectancy (yrs)	10	20	37.5
Life Expectancy (hrs)	4000	8000	15000
Acquisition Cost	$193,621.00	$193,621.00	$193,621.00
Hourly O&M Cost	$35.00	$35.00	$35.00
Annual O&M Cost	$14,000.00	$14,000.00	$14,000.00
Life Cycle O&M	$140,000.00	$280,000.00	$525,000.00
Total LCC	$333,621.00	$473,621.00	$718,621.00
Annualized LCC	$33,362.10	$23,681.05	$19,163.23

Table 6-6: Motor Grader Life Cycle Cost Analysis

D7R Dozer Average Operating Conditions			
Constant 1998 $	**10 yr Life**	**20 yr Life**	**15000 hr Life**
Assumed Annual hours of use	500	500	500
Life Expectancy (yrs)	10	20	30
Life Expectancy (hrs)	5000	10000	15000
Acquisition Cost	$325,026.00	$325,026.00	$325,026.00
Hourly O&M Cost	$57.00	$57.00	$57.00
Annual O&M Cost	$28,500.00	$28,500.00	$28,500.00
Life Cycle O&M	$285,000.00	$570,000.00	$855,000.00
Total LCC	$610,026.00	$895,026.00	$1,180,026.00
Annualized LCC	$61,002.60	$44,751.30	$39,334.20

Table 6-7 Dozer Life Cycle Cost Analysis

Based on the assumed annual use for each of these pieces of equipment, a life expectancy of over 20 years would be acceptable. However, as discussed in a previous chapter, one of the major problems encountered with equipment is lack of use. The equipment tends to break down more when it is not used regularly. Finding the optimal level of use of the equipment that minimizes life cycle cost and maximizes life expectancy provides an area for future study.

VII COST BENEFIT ANALYSIS: ALTERNATIVE METHODS TO OBTAIN EQUIPMENT

A. INTRODUCTION

Currently the Marine Corps purchases all of their construction equipment from domestic companies such as Caterpillar, Case, John Deere, and Sparrow. The equipment is stored and maintained by the battalions. When the equipment is needed to support training exercises and contingency operations, it is transported from the battalion locations to the required destinations via military or commercial means. The cost for the transportation of this equipment comes from operational funds. To avoid much of this cost, we believe there are several good alternative options to the traditional method of owning equipment and transporting it to the operational field. They include the use of renting equipment on an as needed basis or leasing equipment for long term needs over and above the basic operational allowance. The General Service Administration and Foreign Suppliers both offer immediate ways to meet contingency requirements. This chapter will address some of the costs and benefits associated with renting, leasing and owning equipment. It will also provide a brief description and summary of some other cost effective alternatives that the USMC might consider for meeting their equipment requirements.

The purpose of a cost benefit analysis is to compare and evaluate alternatives that can provide a solution to a specific required operational capability. Typically selection criteria are defined which provide for selecting the best value alternative to meet the identified need. For the equipment in this study, best value is generally determined based upon readiness, long term supportability of the equipment, production scheduling and the lowest acceptable life cycle cost.[87] Our study reviewed the USMC's current LCC methodology and recommended that the USMC consider using a longer life expectancy for their equipment. This will reduce their annual Life Cycle Costs and reduce the required up front total procurement dollars.

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[87] MARCORSYSCOM, Combat Support and Logistics Equipment Branch. *Abbreviated BCA for the Scraper, Tractor 621-B.* 3 Jan 2001.

B. ALTERNATIVES TO CONSIDER

1. Individual Cost-Benefit Analysis

An in depth evaluation of alternatives to provide the required operating capabilities defined by the USMC for each piece of equipment is necessary in order to identify the most cost effective method to update the current inventory with limited funds. Some viable alternatives to evaluate are:

- Status Quo
- Inspection and repair of equipment only as necessary
- Service Life Extension Program Opportunities (using MCLB Depot or contractor)
- Combinations of SLEP and new acquisition
- Alternative technologies
- Sharing or Interservice agreements between services
- Combinations of ownership/rent/lease

The overall goal of the analysis would be to provide data that would help the USMC determine the best solution to meeting the ROC. The evaluation should include an evaluation of the LCC for the equipment, comparison of the alternatives and a market analysis to determine the capabilities within the commercial market to meet the requirement. These alternatives would also require updating of the requirements documentation, of which some date back to 1976.

2. Renting Equipment

The last alternative listed above, that of a combination of ownership, rental or leasing represents the most promise to reduce the future procurement requirement. However, this alternative will require the USMC to clearly identify what is considered the minimal amount of equipment required at the unit level to maintain training and operational efficiency of its combat engineers. Contingency, surge and other operational requirements such as scheduled exercises could be met through rental or lease options.

Renting is a way to acquire equipment for periods of less than a year. At the end of the rental agreement the equipment is returned to the owner for maintenance and storage. There are no standard rental rates for the DoD. Rental providers determine these rates locally. Using rental equipment for training exercises and contingency operations is a new concept and seldom used. There is little data on how well it has been working for the Marine Corps and is an area for further study.

Although a full cost benefit analysis was beyond the scope of this study, we did perform a very limited market analysis to obtain rental prices for the equipment in order to determine whether this option is cost effective for the USMC to pursue. Using the same assumptions for rental as were used for ownership (annual hours of use), our analysis shows that renting could be a cost effective alternative and should be explored in more detail. However, detailed analysis should be based upon actual numerical and operational requirements for equipment at each unit. Table C-2 in Appendix B summarizes the rental cost data we collected, and the table below summarizes our findings in terms of total LCC to own the equipment versus renting the equipment for both a 10 and 20-year life cycle. Constant dollars were used for this analysis.

	10 Year Life Cycle		**20 Year Life Cycle**	
	Own Equipment	**Rent Equipment**	**Own Equipment**	**Rent Equipment**
Scraper	$1,180,224.00	$779,057.00	$1,903,794.00	$1,558,114.50
Grader	$395,756.00	$216,700.00	$563,036.00	$433,400.00
D6R (1150) dozer	$349,568.00	$316,625.00	$550,818.00	$633,250.00
D7R dozer	$610,026.00	$454,125.00	$895,026.00	$908,250.00

Table 7-1: Rental versus Ownership cost

The table shows that renting equipment over a ten-year period will consistently result in savings. Renting over a 20-year period is not always cost effective. This analysis used weekly rental rates for comparison. Additional savings can be obtained if monthly rates are used.

One major limitation of our analysis is that the rental prices do not include delivery or pick up of the equipment. The cost for freight and delivery is dependent on the location of the rental equipment and can add significantly to overall costs.

Additionally, our analysis does not consider the cost for a contractor to maintain a certain inventory on standby to meet Government needs at any given time. This could be an issue in an environment of uncertainty with respect to how often a unit will actually need the equipment. These limitations need to be considered if the USMC determines to research this opportunity.

There is no doubt that the commercial sector is capable of providing the required equipment. According to one study, "The rental market has grown 23 % since 1984, with over $9.6 billion in revenues in 1999"[88]. The following data from the same study summarizes this growing market:

- UNITED RENTAL: $2.9 billion in inventory, 722 locations in 45 states
- Hertz Rental: $1.6 billion in inventory, 287 locations in 46 states
- National Equipment: $600 million inventory, 181 locations in 35 states
- PRIME AND RSC: $700 million inventory, 315 locations in 31 states
- Nationsrent: $1.1 billion in inventory, 190 locations in 27 states[89]

A more in depth market analysis of the specific geographical areas in which the equipment is needed should be conducted to determine overall availability.

Rental of equipment offers several potential benefits to the government. The most obvious being the ability to reduce total inventory and overall capital investment while still meeting their operational requirements. Maintenance and repair costs are typically the responsibility of the owner not the renter, therefore reduced operating and maintenance costs are another significant benefit to renting equipment on an as needed basis. The availability of the latest technological advances in construction equipment is another benefit to renting vice owning equipment. There should be a corresponding decrease in infrastructure required to maintain and store the equipment as well.

A significant disadvantage to renting is the potential of not having equipment available when you need it. Spot availability in the market may not match the military's operational tempo. However, there are several contracting methods that could address

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[88]Private Finance Initiative Brief. www.quickplace.marcorsyscom.usmc.mil/Quickplace/family_of_construction_equipment/

[89]Private Finance Initiative Brief. Marine Corps Systems Command

this disadvantage. Additionally, hard use of the equipment could still result in Government liability for repair.

Another area the government would need to consider when renting equipment is the potential for sabotage and terrorist acts. Although the risk may be minimal, renting equipment does increase the risk when compared to ownership and maintaining custody of the equipment and this risk should be addressed.

3. Leasing

Leasing is a way to provide a good or service for money over a period of time greater than one year. Civilian construction equipment leases usually last three to five years with an option to purchase the equipment at the end of the lease. There are currently no lease agreements between Caterpillar Inc. and the Department of Defense or any branches of service.[90]

In the civilian sector, leasing has become a popular alternative to purchase of capital equipment. Leasing provides several advantages to the lessee depending upon the type of lease executed. For this type of equipment, the Government should be able to execute an operating lease, which would require the lessor to provide all maintenance and upkeep of the equipment. Unfortunately we were unable to obtain military lease rates for this study. Generally a NPV analysis of the lease versus buy option is performed to determine if the lease is advantageous to the Government. The Federal Acquisition Regulation Part 7.401 requires the following factors to be considered for lease options:

- Estimated length of the period the equipment is to be used and the extent of use within that period.
- Financial and operating advantages of alternative types and makes of equipment.
- Cumulative rental payments for the estimated period of use.
- Net purchase price.
- Transportation and installation costs.
- Maintenance and other service costs.
- Potential obsolescence of the equipment because of imminent technological improvements.

[90] Lynes, David. Caterpillar Inc., Peoria, IL. Telephonic Interview, 28 May 2003

The following additional factors should be considered, as appropriate, depending on the type, cost, complexity, and estimated period of use of the equipment:

- Availability of purchase options.
- Potential for use of the equipment by other agencies after its use by the acquiring agency is ended.
- Trade-in or salvage value.
- Imputed interest.
- Availability of a servicing capability, especially for highly complex equipment; *e.g.*, can the equipment be serviced by the Government or other sources if it is purchased?

The FAR generally prefers purchasing to leasing. It states specifically that "Agencies should not rule out the purchase method of equipment acquisition in favor of leasing merely because of the possibility that future technological advances might make the selected equipment less desirable." Additionally it clearly specifies that if a lease is justified, a lease with option to purchase is preferable, and long term leases should be avoided, but may be appropriate if an option to purchase or other favorable terms are included. [91]

Leasing is generally a cheaper alternative to renting for long-term needs because the rates are lower. Additionally, leasing ensures the availability of the equipment when it's needed, however, this requires the corresponding facilities to maintain and store the equipment.

4. Contracting

There are several different types of contracting vehicles that could be explored to meet equipment requirements beyond the operational allowance of a unit. This section briefly discusses the responsibility and capabilities of the General Services Administration (GSA), delivery order contracts and indefinite delivery contracts as options for further study in supplying the equipment needs of the USMC.

a. General Service Administration

In 1949, Congress enacted the Federal Property and Administrative Services Act establishing the General Service Administration (GSA) as a central

[91] FAR Section 12.4.

organization to "provide an economic and efficient system for the procurement, supply and disposal of surplus property, and performance of related functions." [92] There are currently 16 construction equipment companies with GSA Schedules. These companies range from international powers such as Caterpillar to local small businesses such as Vermeer Sales of Oklahoma, Inc.

Depending on the mission requirement, the Marine Corps could use each of these companies in different ways. For example: if the Marine Corps is planning a two week training exercise near a Vermeer outlet, they could rent the appropriate equipment for the duration of the exercise and then return it to the outlet. This would reduce transportation, storage and maintenance costs for the battalion involved. On a larger scale, when the U.S. goes to war and the Marine Corps needs equipment, they could rent, lease, or buy this equipment from any number of commercial suppliers. If the commercial supplier is on the GSA schedule, they would be expected to provide the equipment to the destination specified by the Marine Corps or TransCom. Contingency contracts would have to be established with proper incentives to ensure the appropriate equipment was available when required.

b. Delivery order contract

A delivery order contract means a contract for supplies that does not procure or specify a firm quantity of supplies (other than a minimum or maximum quantity) and that provides for the issuance of orders for the delivery of supplies during the period of the contract. Although this type of contract is typically used for manufactured supplies, there is the potential for it to apply to construction equipment in the sense of a guaranteed rental agreement. The USMC could specify a minimum number of hours of use per type of equipment, based upon planned exercises. The contractor would have to be prepared to provide the equipment for use when requested, at the rate agreed upon in the contract.

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[92] www.gsa.gov

c. Indefinite-delivery contracts

There are three types of indefinite-delivery contracts: definite-quantity contracts, requirements contracts, and indefinite-quantity contracts. The appropriate type of indefinite-delivery contract may be used to acquire supplies and/or services when the exact times and/or exact quantities of future deliveries are not known at the time of contract award. Indefinite-delivery contracts allow Government stocks to be maintained at minimum levels and direct shipment to users. They also allow flexibility in both quantity and delivery scheduling. They are also useful in situations of uncertainty in that services can be ordered after the requirements materialize. Again the idea here is to apply this type of contract to the service of providing equipment for use and return.

d. Indefinite-quantity contracts

An indefinite-quantity contract provides for an indefinite quantity, within stated limits, of supplies or services during a fixed period. The Government places orders for individual requirements. Quantity limits may be stated as number of units or as dollar values. Indefinite-quantity contracts are used when the Government cannot predetermine, above a specified minimum, the precise quantities of supplies or services that the Government will require during the contract period, and it is inadvisable for the Government to commit itself for more than a minimum quantity.

e. Job Order Contracts.

A Job Order Contract is a competitively bid, indefinite quantity contract. It has been used successfully by the Government to perform services related to modernization, maintenance, repair, alteration and construction of infrastructure, buildings, structures or other real property. The contract includes a collection of detailed repair and construction tasks and specifications that have established unit prices. This type of contract could be utilized to specify rental rates for specific types of equipment.

5. Private Finance Initiative (PFI)

Private finance began in Great Britain in 1992. It is an initiative being explored by many countries to obtain best value for money by using commercial best practices and fleet-management skills.[93] PFI offers benefits to the public sector, private business and users. The public benefits by obtaining the expertise of private business and reduced costs over the life of a project, private sector benefits through new business, and users benefit through improved service. Applying this initiative to construction equipment entails that the contractor provides complete management of the equipment. This includes having the facilities to store and maintain the equipment, providing daily management of all equipment including dispatch and transportation, and providing all levels of maintenance, to include spare parts, training, mechanics and operators. Essentially, the contractor takes on all responsibility for providing war and peacetime earthmoving operations. PFI differs from privatization in that the aim of PFI is to encourage private investment in major public projects - projects that would have previously relied on money raised from taxation.

Under PFI, a group of companies called a consortium, designs, builds and finances the requirement. The consortium may also provide some of the support services for the customer. In return the customer (USMC) pays a monthly fee for the use of the equipment. The fee may help to cover the manufacturing costs, the rent of buildings, the cost of the support services and the risks transferred to the private sector.

The appeal of PFI is that new equipment can be obtained sooner than if the USMC relied solely on money from the Government, the cost of the new equipment does not have to be paid as one lump sum and the scheme should be less costly over the life of the equipment. The USMC would also benefit from the knowledge and experience of private sector companies to make the best equipment selection for a given operational need.

To implement PFI, the USMC would need to develop its own scheme for obtaining equipment for its operational need. This should be developed and costed as if it was going to be the best solution. The USMC solution is then used as a comparison

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[93]KAJIMA News and Notes. *Private Finance Initiatives, Transforming Public Works*. Vol 24. www. Kajima.co.jp/topics/news_notes/pdf/v24.pdf.

against the private sector consortium schemes, ensuring all the USMC defined requirements have been met and value for money will be achieved. A PFI partner is only selected if they offer a better value for the money.[94]

C. GLOBAL MARKET AND COMMERCIAL AVAILABILITY OF EQUIPMENT

A preliminary research of GSA scheduled companies indicates that the world's construction equipment supply is sufficient to meet any future contingency requirement. Additionally, the global marketplace offers numerous GSA certified companies with redundant capabilities, i.e. inventory and distribution capabilities. Examples include Caterpillar, John Deere, and Grove; all who maintain a certain level of inventory and have global distribution capabilities. These redundancies lessen the risk the Marine Corps will face if adopting to use the contingency logistics.

An alternative to GSA certified companies is to use foreign companies to meet the Marine Corps' construction equipment requirements. There are numerous companies located throughout the world that manufacture and distribute construction equipment. A preliminary review yielded the following potential suppliers: Terex (Australia); Volvo (Sweden); Kubota, and Hitachi/ Kenki (Japan). Including foreign providers in the mix of potential providers increases our options, but also brings with it political uncertainty.

In our opinion, moving acquisition of construction equipment into the civilian market poses no significant threat to the US Defense Industry. The construction equipment items of our study are considered commercial items and can be viewed as commodities available in the global marketplace. Consistent with Chairman of the Joint Chiefs of Staff Instruction 3110.13A, construction equipment items can likely be best met "by leveraging the competitive and global marketplace" to procure them at the lowest cost to the taxpayer. While it is likely that many "lowest cost" alternatives feature U.S.-produced equipment, the optimum solution could easily include the global marketplace.

94 About Private Finance Initiatives. The Vanguard Project. www.vanguardhealth.co.uk/about8.htm

D. SUMMARY

Unfortunately we were not able to obtain reliable cost data for quantifying the true costs of owning the equipment. Our analysis is limited to a general discussion of the advantages and disadvantages of the options available for further study and analysis. However, our research does show that renting and leasing are viable options that should be investigated in much greater detail for a financial comparison to the status quo of owning the equipment. The construction equipment under consideration is all commercially available on a global scale and the preliminary research conducted in this study does indicate that it would be cost effective for the USMC to further investigate these options.

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VIII FINDINGS, RECOMMENDATIONS, AND CONCLUSIONS

A. INTRODUCTION

We sought to determine the correct inventory of engineer construction equipment that should be maintained at the Marine Expeditionary Force level, taking into consideration the current inventory levels, operational tempo, prepositioned war-stock, MEU deployment cycles, and the ability of the commercial industry to provide the Marine Corps equipment as required. We developed models to estimate the usage and availability of this equipment and costs of maintaining and renting equipment as an alternative. This chapter includes conclusions, and recommendations that should be considered when making the decision to change the current engineer construction equipment levels.

B. FINDINGS

1. Gathering data during this project's time frame was hampered due to operations in support of Iraqi Freedom. The appropriate personnel needed to answer questions concerning construction equipment were deployed. As such we relied on MIMMS as our primary source of data.

2. The Marine Corps has not been consistently tracking hours or mileage in MIMMS.

3. Maintenance data identified within MIMMS does not contain the specificity to allow for any reliable trend analysis.

4. The current requirement documents used for the engineer construction equipment are outdated and lack the ability to identify the true requirement for the each piece of equipment

5. The USMC established a generic life expectancy of ten years for the "Family of Construction Equipment."

6. The Marine Corps lacks standards to facilitate planning engineer construction missions

7. JTF-6 and SouthCom currently use commercial rental agreements to support operations in their AOR.

8. There is sufficient global support for renting, leasing or obtaining construction equipment worldwide on an as needed basis.

C. RECOMMENDATIONS

1. Begin tracking hours of use or mileage for all construction equipment.

2. Begin ensuring that maintainers and MIMMS clerks are using the proper maintenance action codes and descriptive explanations in the remarks field to assist any future analysis.

3. Update all requirement documents to reflect the USMC’s 21st Century Strategic Plan.

4. Redefine the Marine Corps' Engineer's Table of Equipment to only contain a small inventory for training at the MEF level and to support Marine Expeditionary Unit deployments.

5. Dispose all excess heavy construction equipment within the MEF's.

6. Maintain the current Table of Organization for engineer units (Maintain the quantity of Marines currently assigned to engineer units)

7. Support all training/operational requirements above the training allotment with commercial contracts.

8. Conduct a market analysis to determine the availability and interest within the private sector for this type of initiative.

9. Explore contingency contracting by performing pilot contracts with a few select construction equipment suppliers.

D. CONCLUSION

Our research has identified actions the Marine Corps can take to better define their requirements for engineer construction equipment inventory. We have also shown that there are potential advantages and sufficient capacity within the global marketplace to meet USMC engineer construction equipment requirements. It is our recommendation that the Marine Corps immediately begin to use these suppliers to start saving on transportation and maintenance costs until the operational allowance can be defined.

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APPENDIX A- EQUIPMENT DESCRIPTIONS

Introduction. Engineer construction equipment is used for earthmoving projects. The prime earthmovers are the dozer and scraper with a grader for finish work.

Crawler Tractors:

Crawler tractors, commonly called bulldozers, are the workhorses of construction. They are used to cut haul roads; move dirt and hard-packed banks, trees, and rocks; and on numerous other jobs. A bulldozer is simply a crawler tractor with a straight blade mounted on the front that is used for pushing objects or materials forward. Once the blade is removed and the machine is used as a towing unit, it is referred to as a tractor.

Crawler tractors are classified according to weight. The Marine Corps classifies crawler tractors into three classes for easy identification; light, medium, and heavy. For example, D6 is in the light class, D7G is a medium class, and D8 is in the heavy class. The Marine Corps maintains the light and medium tractors in its inventory (See figures A-1 and A-2)

Figure A-1 Light Crawler Tractor (B2460)

Description. The light crawler tractor is a fully tracked, diesel engine driven tractor with a hydraulically operated angle blade and winch; it is air transportable.[95] The light crawler tractor grader is commercially available today. The basic dimensions are length - 109", width - 115", height - 109.3", weight 32,000 lbs; and capacity 2.6 CY/H (loose). The commercial off-the-shelf item with service modifications for water fording can fulfill Marine Corps requirements. Manufacturers producing candidates are: International TD15C; Caterpillar D6C; Fiat Allis HDllB; Case 1450; and Komatsu D65A6.

[95] Earthmoving Operations, Field Manual 5-434, 2000

Figure A-2 Medium Crawler Tractor (B2462)

Description. The medium crawler tractor is a diesel powered, full-tracked, medium size bulldozer.[96] The basic dimensions are length - 273", width - 144", height - 132", weight 50,000 lbs and capacity 5.5 LCY/H (loose). The medium crawler tractor is commercially available today. The commercial off-the-shelf item with service modifications for water fording can fulfill Marine Corps requirements. Manufacturers producing candidates are: Caterpillar D8-K; Fiat-Allis HD-21B; International Harvester TD-25C; and Terex 82-30B.

[96] Earthmoving Operations, Field Manual 5-434, 2000

Scrapers:

Scrapers are designed for loading hauling and dumping on long-haul earthmoving operations. The distinct advantage of the scraper in earthmoving is its ability to self-load, haul, and spread in one continuous cycle. Although capable of working alone, the tractor-scraper combination is generally supported with supplementary pusher tractors, and graders at the work site (See figure A-3).

Figure A-3 Scraper-Tractor (B1922)

Description. The Scraper Tractor (Model 621-B) is a wheeled, diesel engine driven tractor with a single engine self-loading open bowl.[97] The basic dimensions are length - 510", width - 138", height - 135", weight 70,458 lbs and hauling capacity 14 LCY. The Scraper Tractor is commercially available today. The commercial off-the-shelf item with service modifications for water fording can fulfill Marine Corps requirements. Manufacturers producing candidates are: Caterpillar Model 621G; Terex TS14B; Fiat Allis 161.

Graders:

Graders are multipurpose machines used primarily for general construction and maintenance of roads and runways. When properly used, the grader can be employed for

[97] Earthmoving Operations, Field Manual 5-434, 2000

crowning and leveling, mixing and spreading materials, ditching and bank-sloping and sidecasting material.

Figure A-4 Motorized Road Grader (B1082)

Description. A self-propelled grading machine (Model 130G) powered by a diesel engine. It is rubber-tired, four-wheel drive, and has an articulated frame and front- wheel steer design.[98] The basic dimensions are length - 327", width - 95", height - 127", weight 30,790 lbs and hauling capacity 14 LCY. The heavy, motorized road grader is commercially available today. The commercial off-the-shelf item with service modifications for water fording can fulfill Marine Corps requirements. Manufacturers producing candidates are: Caterpillar Model 13OG; John Deere JD770; Clark, Austin Western Model Super 301.

98 Earthmoving Operations, Field Manual 5-434, 2000

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APPENDIX B – Production Factors and Rental Rates

Percent Grade Correction Factors
(FM 5-434 Figure 2-15)

% grade	Correction factor	D7G
-30	1.6	1.25
-20	1.4	1.22
-10	1.2	1.15
0	1	1
10	0.8	0.85
20	0.6	0.65
30	0.4	0.4

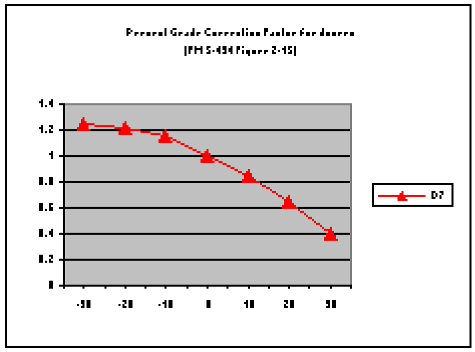

Figure B-1 Army Grade Correction Factors

Army Operating zones
(FM 5-434 Chapter 1)

Power	max power	adverse conditions, steep slopes, rough terrain
slow speed	avg power	better conditions, short haul distances
high speed	min power	good conditions, longer hauls and higher speeds achievable

Table B-2 Army Operating Zones

CONSTRUCTION EQUIPMENT RENTAL PRICES

EQUIPMENT	TERMS	QUINN COMPANY SALINAS, CA	HAWTHORNE RENT-IT SERVICE CARLSBAD, CA	ALBAN TRACTOR CO. INC. DUMFRIES, VA
TRACK TYPE TRACTORS				
D6R	DAILY	NA	$ 670	$ 775
	WEEKLY	$ 2,533	$ 2,680	$ 2,300
	MONTHLY	$ 7,600	$ 8,040	$ 6,900
D7R*	DAILY	NA	$ 1,200	$ 1,250
	WEEKLY	$ 3,633	$ 4,800	$ 3,700
	MONTHLY	$ 10,900	$ 14,400	$ 11,000
MOTOR GRADERS				
140H (12H AT ALBAN TRACTOR)	DAILY	NA	$ 525	$ 765
	WEEKLY	$ 2,167	$ 2,100	$ 2,300
	MONTHLY	$ 6,500	$ 6,300	$ 6,900
SCRAPERS				
613C II	DAILY	NA	$ 675	$ 1,000
	WEEKLY	$ 3,833	$ 2,700	$ 3,000
	MONTHLY	$ 11,500	$ 8,100	$ 9,000
EXTRA CHARGES			1% ENVIRONMENTAL FEE ON ALL RENTAL EQUIPMENT	

*Hawthorne Rent-It Service does not rent a D7R track typ tractor. Prices given are for a D8R.

Table B-3 Rental Costs for Construction Equipment

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Marine Corps, Installations and Logistics web site, http://www.hqmc.usmc.mil/ilweb.nsf

These impacts have been highlighted to us through interviews with HQMC personnel and by personal experiences of Major Christopher Zuchristian (1302, Combat Engineer Officer). We will need to validate them during our research.

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